Contractor's Report to the Board

Postconsumer Resin Quality Assurance and Testing Protocol

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Executive Summary

This report proposes a quality assurance program for postconsumer resins (PCR). The objectives of the overall research are to evaluate the postconsumer plastic processors in California and their respective quality assurance programs and to propose a model quality assurance program for postconsumer resins. The best quality procedures from companies in the United States and Europe were used to develop PCR quality control guidelines and testing protocol. The quality control system is applicable to the major recycled plastics, for example, LLDPE, LDPE, MDPE, HDPE, PP, PS, and PET.

The PCR quality guidelines are useful for a range of products, including trash bags, rigid packaging, and plastic lumber. The guidelines can be used as a basis for film processors and PCR producers to establish specific specifications for a particular product. The film processor and PCR manufacturer must agree on the quality control values that are suggested in the guidelines. The PCR quality guidelines and testing protocol do not guarantee that a PCR material can be used for commercial products, as this must be agreed to by the companies involved in the contractual relationship. The PCR guidelines are used during PCR manufacturing operation when the incoming plastic material is received, processed, and packaged in a Gaylord. A Gaylord is a cardboard box that measures 1 yard by 1 yard by 1 yard and is filled with plastic pellets. The study suggests different quality levels of PCR with different levels of documentation, specifications, and testing requirements. The guidelines describe five quality levels of postconsumer resin (PCR), ranging from quality level 1 for near-virgin plastic quality to quality level 5 for near-recycled plastic lumber quality.

Once specific quality specifications are established between PCR supplier and processor, trash bag manufacturers may use PCR with quality level of 1. Thicker film and sheet may use PCR with quality grades of 2 or 3, depending upon the plastic processors' specifications. Trash bag manufacturers can use PCR with quality levels of 1, 2, or 3. Rigid packaging manufacturers can use PCR with quality levels of 4 or 5. A key quality characteristic of grade 4 PCR is improved environmental stress cracking resistance. Plastic lumber manufacturers can use materials from grades 4 and 5. The PCR quality guidelines encompass all five grades of PCR materials, though different grades will have different testing standards, material specifications, and process control. The quality assurance program can help PCR manufacturers improve the quality of PCR and provide them with a more consistent product that will ultimately lead to higher profitability and increased PCR usage in California.

The effects that the guidelines and testing protocol have on the quality of the PCR produced at two PCR manufacturing facilities in California were evaluated by measuring the density, melt index, pellet count, and contamination of the PCR produced before and after the guidelines were used. Customized quality procedures, based on the PCR guidelines, were provided to both production operations. PCR produced at one company in October 2004 displayed a quality improvement versus PCR produced in August 2004.

The quality of the PCR exhibited less variation in pellet count and density, but more variation in melt index over a two-month span. The company had difficulty obtaining sufficient quantity of postconsumer LLDPE and ran out of the recycled material during the testing phase in October 2004. This shortage of postconsumer plastic reduced the quality of the PCR produced in October 2004. A second PCR production facility also experienced difficulty in finding LDPE postconsumer plastic but was able to produce PCR with polypropylene from automotive bumper covers and with polystyrene from used coat hangers.

PCR produced in October 2004 at the second company facility displayed a quality improvement versus PCR produced in August 2004. The quality of the PCR exhibited less variation in melt index and density, but more variation in pellet count during a two-month span. Both manufacturing facilities recognize the importance of establishing and maintaining a quality assurance program during the production of the PCR. The PCR quality guidelines and testing protocol helped the two companies improve the quality assurance programs at their facility and also slightly improved the quality of the PCR produced.

Additional improvements are needed at each facility to further integrate the quality guidelines into their quality assurance programs. Additional work is needed to identify and locate recyclers of postconsumer plastic materials. A third PCR production facility the company visited in August 2004 went out of business. This facility was not available to implement the PCR guidelines and testing protocol, and it could not provide any PCR material for testing.

Introduction

The California Integrated Waste Management Board (CIWMB) initiated a research program to develop a Quality Assurance Guideline and Testing Protocol for postconsumer resin (PCR) manufacturers in order to improve the quality of PCR. The Department of Mechanical Engineering and Manufacturing at California State University, Chico, was hired to do the research. The objectives in the research project are to evaluate the postconsumer plastic processors in California and their respective quality assurance programs, and to develop a model quality assurance program PCR manufacturers could use to produce high quality PCR. The project is broken down into five steps, which are listed below.

Step 1: Create detailed work plan.

Step 2: Conduct survey of postconsumer post processors in California.

Step 3: Develop Quality Assurance (QA) guidelines.

Step 4: Propose a testing protocol for postconsumer plastic resin.

Step 5: Evaluate effectiveness of the QA Guideline and Testing Protocol.

Step 1. Detailed Work Plan

Plastics are seemingly ubiquitous in the world today. We are living in the plastics age where plastics are replacing metal, wood, paper, and ceramic products in most industries today. These industries include transportation, medical, retail, and electronics. The key feature of thermoplastics is the fact that the material can be heated and formed multiple times. Recycling is one of the advantages of thermoplastics. Commodity thermoplastics include PET or PETE (Type 1), HDPE (Type 2), PVC (Type 3), LDPE (Type 4), PP (Type 5), PS (Type 6), and Other Plastics (Type 7). (See Appendix A for complete names of some common plastic resins.)

The number enables containers to be collected and sorted for recycling by plastic type. Then the plastics of the same type can be reprocessed into PCR. The two types of recycling sources are postindustrial and postconsumer recycling. Postconsumer plastics are separated from household trash by the consumer and given to a recycler for processing.

In 2003, the total annual postconsumer plastic bottles recycled in the United States increased to an all-time high of 1,667 million pounds.[1] The majority of recycled plastic is polyethylene terephthalate (PET or PETE) or high-density polyethylene (HDPE). PET is used for bottles of soda pop and other beverages. The overall annual recycling rate of PET bottles in California, defined as the amount of PET bottles recycled divided by the amount of PET bottles sold in California, increased slightly to 22.1 percent in 2001 as compared to the amount recycled in 2000.[2]

Recycled PET can be remolded for strapping materials and fibers for clothing or carpeting. HDPE is most commonly used for plastic milk jug containers. The overall annual recycling rate of HDPE bottles in California increased slightly from the previous year to 23.2 percent in 2001.[3] HDPE can be used as a plastic material in plastic pipe, bottle, and lumber applications. The increase in collection of recycled plastic materials is a result of the improved curbside collection methods used in the United States during the last decade. In 2001, the amount of collected recycled plastic was approximately six times the amount collected in 1989 when the statistics were first compiled.[4] Unfortunately, for the sixth year in a row, household recycling of bottles is the weakest source of plastic bottles. This is due in part to poor consumer education on plastics recycling.

U.S. Plastics Recycling

The state of North Carolina developed a framework for assessment of plastics recycling potential.[5] It includes estimations of the quantity of waste that could be available for recycling, assessment of the state's recycling technology including the manufacturing capacity, and evaluation of potential markets for products manufactured from recycled plastics. They found that the state's manufacturing capacity is adequate for the proven technology, but that an adequate market for the commingled plastics does not exist.

A similar result was found for plastic bottle reclamation in the U.S., where the process of reclaiming plastic bottles is mature and a sufficient number of manufacturing companies exist to process recycled plastic materials. The capacity of plastic reprocessors exceeds the supply of plastic materials. Domestic reclamation capacity exceeds utilization by 35 percent for PET and 42 percent for HDPE.[6] The excess capacity can be reduced if more households are able to recycle the PET and HDPE plastic bottles and send them to the waste management collectors. Other types of plastics are not used in high enough volume to impact the recycling rates. In fact, if all of the other plastics, Type 3 through Type 7, were recycled, the amount of recycled materials would not significantly change the all-materials recycling rates by more than 1 percent.[7]

European Plastics Recycling

European companies are also concerned with the effect plastics have on the waste stream and the need for increased recycling. In 1995, the European Commission Life program provided grants to plastic bottle recyclers and collectors in order to develop a sustainable system for plastic bottle recycling.[8] The study found that plastic bottle collection and mechanical recycling is environmentally desirable, since it contributes to reductions in energy usage, solid waste disposal, and certain emissions. The study also found the most significant barrier to recycling is the limited development of collection schemes for postconsumer plastic bottles. The U.K. could make significant increases in bottle collections and still provide outlets for the PET and HDPE recycled materials.

This result is similar to the problem in the U.S. of efficiently collecting plastic bottles at households. The U.K. study illustrates the needs for improved standards on PCR materials to address the belief of some users that recycled plastics have inferior properties and result in a sub-standard plastic product. One study in the U.K. demonstrated that the quality of PCR HDPE blow-molded bottles exceeds bottles made from virgin plastic.[9] The research also established that polypropylene obtained from automotive shredder residue displayed sufficient material strength for reprocessing.

The European Union Packaging and Packaging Waste Directive of 1994 called for the recovery of 50 percent to 65 percent by weight of total packaging waste with an overall target of 25 to 45 percent recycling. The directive specified a specific target of 15 percent recycling for each packaging material by July of 2001.[10] The directive resulted in a British law that opted to recover 50 percent and recycle 25 percent of packaging by 2001, with a 15 percent minimum recycling rate for each material. Recycling of postconsumer PET, PVC, and HDPE in the U.K. has made significant contributions to meeting the national target of the recycling directive, but more work is needed to improve compliance with the law.

The survey from the research study provides an overview of plastic bottle recycling and recommends help from the government to increase the number of collection schemes in more cities and towns in England, Wales, Scotland, and Ireland. Help is needed to coordinate transfer stations, material recycling facilities, and bailing facilities that are close to the collection area. England has shown dramatic increase in the collection of plastic materials for recycling and has initiated several programs to generate the required infrastructure. England, like the U.S., has an overcapacity of recycling processors and is required to import waste plastic from Europe.

California Plastics Recycling

According to the 2003 Waste Characterization Study, the amount of plastics disposed in California's waste stream was 3,809,699 tons, or 9.5 percent by weight. From this, 1,747,659 tons, or 4.4 percent by weight was film. Plastic packaging containers represented 612,153 tons, or 1.5 percent by weight of California's waste stream.

The Rigid Plastic Packaging Container Program of California, administered by the California Integrated Waste Management Board, mandates that companies whose products are sold in California be made of at least 25 percent PCR. Because using 25 percent PCR might be technologically infeasible, such containers could be eligible for waivers under this condition. However, containers waived under this condition must comply with another compliance option. The CIWMB recognizes the technological hurdle associated with the use of PCR in certain applications and makes allowances as necessary.

California's Trash Bag Recycled Content Act, passed in early 1990s, requires plastic trash bag manufacturers selling trash bags in California to meet one of the following requirements: either the plastic trash bags contain actual postconsumer material equal to at least 10 percent by weight of the regulated bags, or the trash bags must contain actual postconsumer material of at least 30 percent of the weight of material used in all of its plastic products.[11]

In 2002, 24 manufacturing companies were in compliance and 4 companies were in noncompliance with the State law. Those wholesale companies in compliance numbered 183.[12] Some of the companies are having difficulty finding high-quality PCR made from LLDPE that can be used in the manufacturing of trash bags and meet the product requirements of trash bag customers. The industry needs standards to improve the quality of recycled plastic.

Plastics Recycling Business Overview

The growth in the plastics industry has led to a corresponding growth in the plastics recycling business. Legislation mandating recycling has assisted the growth of this business. When virgin plastic prices are high, the prices for recycled plastics are elevated. Correspondingly, when the prices of virgin plastic fall, the selling prices of recycled plastics also are reduced. During the last several years, the prices of virgin and recycled plastics have fluctuated wildly. The price of virgin PET in 1995 was $0.85 per pound and dropped to $0.46 per pound in 1999. The average price of recycled PET was $0.65 in 1996 and dropped to $0.23 by the end of 1996.[13] The 1-billion-pound increase in production of virgin plastic packaging overshadowed the 69-million-pound increase in tonnage of plastic packaging recycled between 1995 and 1996.

During the period from 1990 to 1996, for every additional pound of plastic packaging recycled, the industry produced another 3.7 pounds of additional virgin plastic packaging. In 2000, plastic pellet production in the United States exceeded 100 billion pounds.[14] Many companies were established to provide recycled materials from postindustrial and postconsumer sources. A research report highlighted key business strategies necessary to be successful in the recycling business.[15] The research pointed out that many recycling businesses have survived the turbulent times by developing and maintaining in-house technologies, securing financial or technical support from external sources, and establishing strong business leadership. Fifteen PCR companies that are located in California or Oregon are listed in Table 1.

The manufacturing process of converting recycled plastic into a new plastic product is daunting. Converting recycled plastics to plastic pellets involves sorting, washing, drying, and pelletizing. The most common processing steps include granulation, air classification, washing, separation, rinsing, and drying.[16] The plastics are sorted by either manual or automated identification methods.

The manual method is labor-intensive and requires operators to monitor an assembly line and sort out clear plastic bottles (PET) from the milk containers (HDPE) and colored plastic containers (LDPE, PP, PVC). The automated method can employ one of several analytical techniques, including x-ray fluorescence, mass spectroscopy, Fourier Transform Near Infra-red (FT-NIR) spectroscopy, Fourier Transform medium Infra-red (FTIR) spectroscopy, or tribo-electric analysis, on the recycled plastic materials.

The automated sorting method efficiently and quickly sorts the plastic. One researcher listed the advantages and disadvantages of each and recommended two techniques for use at a large automotive company for plastic bumper materials.[17] Other researchers reported the speed at which spectroscopic techniques can identify plastics with the use of a computer and tabulated spectra. Hundreds of identifications per second can help sort plastics with more than 99 percent accuracy.[18] One researcher reported a throughput rate of 2,000 kg per hour.[19] The sorting efficiency was improved with the development of an automated sensor cleaning system. The washing methods vary from one reclamation facility to another.

In past years several washing facilities were built at great expense. Washing is the most expensive activity of the postconsumer plastic recycling process. The last step in the postconsumer recycling process is melt processing, where the clean plastic material is pelletized and placed in containers for shipments. The quality of recycled materials that are collected from consumers can be poor. The poor quality is attributed to dirt, contaminants, labels, and other plastics that are mixed with the recycled plastics. Thus, the plastic is not separated into its category but is part of a mixture of many types of plastics and other polymers from adhesives on labels. This leads to PCR plastic materials that can have lower mechanical properties than virgin materials.

Table 1. Recycling Companies in California or Oregon [20]

Recycling Company	Location	Recycled Material	Source of Raw Material	Product
PCR Plastic Suppliers				
Bay Polymers	CA	All	Postindustrial	Pellet/flake
Denton Plastics	OR	PE, PP, PS, ABS	Postconsumer/ Postindustrial	Pellet/flake
Joe's Plastic	CA	All	Postindustrial	Pellet/flake sheet
Quantum Resources	OR	All	Postindustrial	Pellet/flake
Recycled6 Inc.	CA	EPS	Postconsumer	Pellet/flake
The Recycling Professionals	OR	EPS	Postconsumer	Pellet
Talco Plastics	CA	HDPE	Postconsumer	Pellet/flake
PCR Plastic Molders				
Clorox Corporation	CA	HDPE	Postconsumer	Bottles
Continental PET	CA	PET	Postconsumer	Bottles
Epic Plastics	CA	HDPE	Postconsumer/ Postindustrial	Plastic lumber
FP International	CA	EPS	Postindustrial	Packaging peanuts
Marko Foam	OR	EPS	Postindustrial	Packaging
Pactiv	CA	LDPE	Postindustrial	Packaging
Timbron International	CA	EPS/PS	Postconsumer/ Postindustrial	Plastic Lumber
Trex	OR	LDPE	Postconsumer/ Postindustrial	Plastic Lumber

Mechanical Properties of PCR

Most of the mechanical properties of PCR materials are lower than for virgin materials because the polymer chains can be broken from the repeated heating and shearing of the plastic in the extruder, exposure to UV, or through stress cracking. The amount of degradation of the recycled plastic could vary from plastic to plastic due to repeated exposures (heat histories) to heat in the extrusion barrel during reprocessing. Polypropylene and polyethylene are known to degrade after multiple heat histories during recycling. Other materials can be less sensitive to reprocessing temperatures. High-impact polystyrene showed little degradation after 30 processing iterations.[21] Melt flow rate, tensile properties, and impact properties changed very little after 30 reprocessing steps. Other researchers found similar insensitivity to heat histories for polycarbonate[22] and nylon-6.[23]

In several cases the mechanical properties of virgin LDPE were reduced with the addition of postconsumer and postindustrial recycled materials if the recycled content was greater than 25 percent.[24] For lower concentrations of commingled PCR the hardness and strength increased, but the material became more brittle. The impact strength, likewise, was reduced for the high concentrations, but unaffected by lower concentrations. The recycled material was a combination of several engineering resins and was used as filler. The resulting mechanical properties are consistent with properties resulting from filler additives. The mechanical properties of virgin HDPE are improved with the addition of postindustrial ABS and PMMA.[25]

Blends of the postindustrial recycle materials with virgin ABS improved the flexural stiffness, tensile strength, and HDT. Alternatively, the melt flow dramatically decreases with the addition of PCR HDPE with injection-grade HDPE and film-grade HDPE.[26] The compounding of PCR HDPE produces a decrease in MFI that is attributed to cross-linking of the HDPE and has a very strong consequence for modulus, yield stress, and impact strength.

The introduction of new high-performance polyethylene plastics can compensate for the property deficiencies in recycled resins. This involves blending recycled HDPE with an environmental stress crack resistance (ESCR) HDPE. Environmental stress cracking can be defined as the initiation of a crack due to a combination of applied stress and contact with a specific liquid.[27] Postconsumer plastics are also affected by ultraviolet (UV) exposure. The UV exposure caused the plastic lumber to whiten on the surface. The thermal cycling of the plastic lumber caused the crystallinity to increase and resulted in increased tensile strength and modulus.

Recycled HDPE can contribute to poor stress crack resistance (SCR). Milk containers and fruit juice bottles are a major source of recycled HDPE. A research paper suggests that PCR HDPE can be used in low-pressure pipe applications at recycled content greater than 50 percent.[28] The recycled HDPE has limited use in high-stress applications. The 100 percent HDPE PCR did not display adequate environmental stress cracking resistance.

The ESCR is acceptable at lower stress levels if 25 percent virgin MDPE is added. The SCR can be improved with the addition of ESCR modifier. Results from a research paper confirmed that the incorporation of a modifier to recycled HDPE increased the stress crack resistance by approximately 100 percent.[29] Stress crack resistance is especially important for recycled HDPE use in plastic pipes. Another researcher concluded that an additive can be added to polyethylene to resist stress cracking.[30] The research found that the stress cracking agent retarded fatigue crack propagation at low stress levels but accelerated crack propagation at higher stress levels.

Research in quality assurance methods for PCR plastics in Europe and the United States are much more limited than for quality standards of virgin plastics. Typically, virgin plastics are produced by very large multinational companies who require very high quality control standards and practices. All virgin plastic manufacturing companies are compliant with ISO 9001[*] standards. Alternatively, postconsumer resins are produced by small- to medium-sized companies that generally do not have the capital investments to institute high-level quality control procedures. The lack of quality standards, though, can limit the use of postconsumer resin materials.

The California Integrated Waste Management Board defined standards of PCR quality for use in trash bags. The standards require PCR manufacturers to meet specifications for moisture, pellet uniformity, contamination, specific gravity, and melt index.[31] Two companies developed quality standards for HDPE PCR[32] and PP PCR[33] that are similar to quality characteristics of virgin plastics. The first researcher presented a quality system that includes quality testing of raw materials, monitoring of melt index, statistical process control of the extrusion process, color analysis, and contamination control. The researcher determined that an effective method for quality control of an HDPE film is to produce a 2-mil test strip and compare it to strips that have a predetermined quality grade.

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[*] International Organization for Standardization quality management standards, www.iso.ch/iso/en/iso9000-14000/iso9000/iso9000index.html.

Other key elements of the quality system are the development of a quality check sheet for incoming materials, color analysis with CIE L-a-b color scale, use of a tight screen pack to trap larger contamination particles, back-pressure measurements across the screen pack, and addition of antioxidants to the PCR.[34] The second researcher demonstrated a successful quality assurance in plastics recycling with a scrap battery recycling plant.[35] The researcher developed a quality system that includes testing of raw materials for impurities and melt index, quality control on process parameters, and after-sales service on the recycled materials.

Recycling of postconsumer PET, PVC, and HDPE in the U.K. has made significant contributions to meeting the national target of the recycling directive, but more work is need to improve the quality of postconsumer materials. A nonprofit company, Waste and Resources Action Programme, that works to promote efficient markets for recycled materials and products in the U.K., published a research report to improve the quality of recycled plastics.[36]

The research identified barriers that are directly related to quality standards or specifications that discriminate against greater use of recycled materials. The barriers were identified based on a telephone survey to 37 companies who are involved with U.K. plastics recyclers. Nine companies were classified as large recyclers. Twenty-two recyclers are considered small recyclers. Six respondents were government agencies. The survey results found that the responses can be split into two categories, one made up of large recyclers (greater than 10,000 tonnes[†] per year) and one of small recyclers. Standards were more important and have more of an impact on the businesses of the large recyclers than of the small recyclers.

The report recommended standards and test specifications for refuse sacks. The standards limit the recycled content to a maximum of 25 percent and have specifications for dart impact, tear strength, and tensile strength. Some recyclers in the U.K. are using 98 percent recycled content for the refuse sacks, but no standards or specifications have been developed. Representatives from the smaller companies reported in the study identified a business concern due to their inability to perform quality testing. They also reported that they do not have the capacity to finance the extra burden of new quality test equipment due to very thin economic margins in the recycling business.

Representatives from the larger companies reported that testing facilities on-site are a basic prerequisite for sustainable involvement in the recycling market. Many respondents to the survey expressed the view that tracking recycled materials from the receipt of incoming materials to processing into PCR pellets of flakes—and then packaging of the final approved product—is essential to any quality assurance system. Most of the respondents from the large recyclers felt that if they were provided with good quality control and testing standard regimes, a competent technician could produce a compound of similar quality tolerance to most virgin materials. Many respondents to the survey warned that almost no quality control exists with many companies even though there are ISO quality management standards to which recyclers could become accredited.

Lastly, the survey revealed that a lack of general culture of quality management exists within the recycled plastics industry even though an excellent quality management culture exists within the mainstream plastics industry.

In the United States, the lack of quality standards and material standards when compared to virgin resins was determined to significantly hinder the use of recycled materials in the electronics industry.[37] A forum, created from electronics manufacturing companies, developed recommendations for improving the quality of recycled materials. Recommendations included

[†] A tonne—or metric ton—is equal to 1,000 kilograms or 2,204.6 pounds.

providing classifications of recycled plastics and establishing grades within the classifications. For each grade of material the standards specify a set of material quality variables or properties; for example, weight, color, plastic type, contaminants, and physical properties. The quality management standards also specify ranges of values for each material quality variable and standard test protocols for measuring quality. The standards also include an inspection process for incoming materials and a process for the manufacturing operation.

Step 2. Quality Survey of PCR Manufacturers

The second phase of the research consisted of a survey of the quality assurance practices at eight postconsumer resin manufacturers in California and one in Illinois. The survey produced results similar to the U.K. survey in that the responses were divided into groups based on the size of the company. In the CIWMB-sponsored survey, the larger companies report having a quality assurance program, while the smaller companies do not. The largest four companies each produce more than 20 million pounds of plastic each year, have well-defined quality procedures, and perform quality tests on a regular basis.

The other five companies each produce between 1 and 10 million pounds of PCR and perform quality tests on an “as needed” basis. Both groups rely upon visual methods to sort and evaluate the incoming recycled material before it is sent into the processing operation. The difference between the large and small PCR manufacturing groups is most pronounced during the compounding process of converting the recycled plastic into postconsumer resin pellets or flakes.

One of the most effective methods to check the quality of the PCR is with a small extrusion-blown-film line. This enables the PCR materials to be blown into a film and then checked for bubble stability, color, odor, strength, and other quality measurements. If the quality is poor then the material can be discarded or blended with conforming material. This technique significantly reduces the risk of material failure at the blown-film production operation.

Based on the survey results, the larger PCR manufacturing companies have a documented quality operation that tracks the manufacturing process with inspection sheets that are included with every lot of material. The smaller companies only document the quality control if problems arise. After the PCR is produced the larger companies test the material for color, odor, melt index, and density.

Most of the smaller companies visually test for moisture and contamination and only perform quality tests if required by the customer. Several of the smaller companies do not perform any quality tests on the outgoing PCR product. One large company produced a high quality LLDPE PCR and demonstrated a quality control procedure that has many characteristics of an effective quality assurance program and many of the elements that are included in an ISO 9001 certification. None of the companies that participated in the survey are ISO 9001-compliant, and none are willing to spend $5,000 to be compliant. An ISO certification company can help manufacturers obtain ISO 9001 certification inexpensively.[38]

The survey of the PCR manufacturers illustrated inconsistent quality control. The quality of PCR can be significantly improved without requiring very expensive equipment by improving the monitoring of incoming plastic as it is converted to PCR, documenting the process parameters, and keeping quality records associated with lot numbers of PCR. An efficient quality control will enable the processors to identify manufacturing concerns before they manifest themselves as quality problems.

A key component of successful PCR manufacturing is the development of a quality assurance system that includes inspection of incoming product, monitoring melt index, measuring contamination, and meeting quality targets for the final PCR product. The quality of the PCR can be measured with a variety of test methods, including melt index, density, quantitative chemical analysis by color (colorimetry), differential scanning calorimetry (DSC), infrared spectroscopy, and tensile testing.[39]

The survey of PCR processors identified three problem areas, for example, poor documentation, incomplete process control, and inconsistent testing of final product. The poor documentation begins with inconsistent quality control of incoming plastic to the PCR manufacturer. The incoming plastic should be inspected and meet a set of material standards.

Thus, problems with quality can be identified at the source and removed from the process. Additional quality standards are needed to improve the quality of the incoming recycled plastic. The incoming plastic can be contaminated with wood, paper, cardboard, metal, PVC, PVDC, and organic items that need to be removed before processing. The improved quality in the plastic used at the beginning of the PCR processing operation will greatly improve the quality of the final product.

The second problem with current quality practices at postconsumer plastic processing companies is incomplete quality control at many of the smaller PCR producers and some of the larger ones. The companies did not appear to have a quality culture wherein quality is a valued and essential business component. The smaller companies and most of the larger companies did not demonstrate a practice of measuring the quality of incoming plastic, nor monitoring the quality of the plastic during the manufacturing operation. Some of the companies reported measuring the quality of the PCR if the customer required it.

The third quality area of concern covers the testing methods for the final PCR product. Standard tests are needed to characterize the PCR by melt flow and density. The testing will enable the customer to better blend the PCR with other similar types of plastics. Other quality tests can be used to better characterize the quality of the PCR if required by the PCR customer. The tests include moisture, residual additives, odor, and contamination.

Survey Results

The results demonstrate the fact that larger companies have more thorough quality procedures than smaller companies. Larger companies can evaluate incoming product per specifications and remove any contaminants present. If the incoming material has too many contaminants, it is rejected and returned to the recycling source. Most of the PCR manufacturing companies perform similar evaluation procedures. The second important area for testing is during processing.

One large PCR manufacturing company has, in place, effective inspection procedures and documentation of incoming materials, excellent process control and documentation of the manufacturing process, and efficient and effective product testing of the manufactured PCR. The last evaluation step is testing of the final product. Most of the large PCR companies evaluate the PCR plastic for melt index, density, and color. None of the smaller PCR companies perform quality testing on final product. None of the companies that participated in the survey reported any chemical testing on the plastic product. Some of the companies did report that antioxidants and virgin plastics are added to enhance the properties of the PCR.

Step 3. PCR Guidelines

A model quality management system can be developed based on the best practices in quality assurance from PCR manufacturing companies who participated in the survey and from published results of the research work in Europe and the United States. The CIWMB-sponsored survey from Step 2 of the research found that quality control standards are needed to improve the quality of PCR for small and large PCR companies, even though they have different approaches to quality control. Also, PCR manufacturing companies do not have the same quality culture as virgin plastics manufacturing companies.

The survey results and literature review indicate that quality control is needed throughout the PCR processing operation, including receipt of incoming recycled materials, processing of the recycled plastic into PCR, and inspection of final PCR product. The quality methods are evaluated by identifying several factors that are needed in order to achieve high quality PCR.

Each of the manufacturing steps that are used to produce PCR requires quality control. The quality control will vary depending on the type of PCR that is produced. PCR can have several different types of customer requirements depending on the intended use of the PCR materials. Trash bag manufacturers who use PCR will have a different set of requirements than manufacturers of rigid packaging or plastic lumber. Rigid packaging products can have product requirements as demanding as film applications. Each of the customers of PCR must be assured that the PCR materials are certified for postconsumer content. Then, the different end-users should be able to get the PCR that meets the needs of their product.

Quality Levels for PCR

Five quality levels of PCR are proposed that range from grade 1 for near virgin plastic quality to grade 5 that has unacceptable quality for trash bag manufacturers but acceptable quality for some rigid packaging and for plastic lumber manufacturers. Quality grades 1, 2, and 3 require the use of stretch film LLDPE, whereas quality grades 4 and 5 can use other plastics, as specified in Material Specifications Level 1 and Level 2. Once specific quality specifications are established between PCR supplier and processor, trash bag manufacturers may use PCR with quality level of 1. Thicker film and sheet may use PCR with quality grades of 2 or 3, depending upon the plastic processors' specifications. Trash bag manufacturers can use PCR with grades 1, 2, and 3. Rigid packaging manufacturers can use PCR with grades of 4 or 5.

The specifications for grade 4 PCR will improve the reliability of the PCR and minimize the stress cracking when the rigid packaging container is produced with PCR and is exposed to oils, paints, or adhesives. Plastic lumber manufacturers can use materials with grades 4 or 5. The five PCR quality grades are further explained in Appendices A, B, and C.

Quality Management System (QMS)

The QMS for PCR is broken down into three major areas during the PCR manufacturing operation: Part 1: Receiving of incoming plastic material, Part 2: Process control during the manufacturing operations, and Part 3: Final product specifications. The new standards include documentation and testing throughout the process in all three areas.

The quality system can be implemented with the establishment of a quality management system at each PCR production facility. Each company can institute a quality policy that fits its company needs and production requirements and is documented in the quality control manual. The policy will include various degrees of statistical quality control methods, inspection sheets, final product testing, lot traceability, and quality audit procedures. The actual raw materials used, process control parameters, and final product specifications are left to agreements between the reprocessor and the customer.

Quality Control System

While quality assurance is defined as methods that a company uses to ensure that a particular product conforms to desired specifications, quality control is defined as specified test and operational procedures that are needed to assure that the product is made to established quality standards.

The quality control system will encompass all five levels of PCR materials, though different levels will have different testing standards, material specifications, and process control. The quality control system will be implemented during three areas of PCR manufacturing; for example, incoming material specifications, process control of manufacturing operations, and final product specifications. The three areas will include data collection with quality records throughout the manufacturing process and material testing procedures during selected phases in the manufacturing process.

The testing procedures and frequencies will vary between the five grades of PCR. The PCR manufacturer can establish which grade of PCR they produce as they select the recycled plastic and pay close attention to the source of the recycled plastic. The manufacturing operation for PCR will be required to maintain quality standards to produce the selected grade of PCR. Appropriate quality tests and procedures will also follow the recycled plastic as it is transformed into PCR. The PCR then can be certified as to the grade of PCM and to the level of quality. The certification is based on documentation that will follow the plastic as it is converted to PCR. The quality control data sheets and material testing procedures can be automated with web-based technology to improve the flow of data.

The quality assurance program is based on proper documentation and testing throughout the manufacturing operation. The implementation can occur in several different ways with varying degrees of automation and technology. The process control charts and inspection sheets can be automated and part of an online quality control process. Training of personnel is an essential component of an effective quality control program with the inclusion of quality control manuals. Each company should add these PCR guidelines to the company’s quality control manuals.

The manuals are highly dependent on the manufacturing company’s operation and should be developed individually at each facility. Corrective actions should also be included with the company’s quality control procedures. Finally, quality audits should be held periodically at each facility to assess the implementation of the quality assurance protocol. Quality audits can include random sampling of plastic material from incoming bales and from the Gaylord boxes and performing the quality tests for the grade level of PCR.

The quality testing protocol will be implemented with a quality control manual that documents the quality system. The quality control manual will include many elements of ISO 9001, including documentation, quality policy, and quality objectives for each company. The quality principles establish ways to track nonconformance in materials and identify and then remove quality problems at the source. The guidelines for quality control will be given to each participating manufacturing company at the end of the research project. Each company can then incorporate the quality manual into the quality system for their respective operations.

The quality manual will include many items that are part of an effective quality management system. The quality manual establishes a quality policy that defines the quality objectives at the company. The manual establishes responsibility for quality control in the manufacturing operations and training for the production workers. The quality procedures encompass inspection procedures with material specification documents and testing procedures with reliable sampling plans.

Step 4. Model Testing Protocol for PCR

A uniform testing protocol was developed for PCR using the PCR guidelines. The testing protocol provides testing methods that are consistent, reliable, practical, valid, reproducible, and economically feasible. The proposed testing standards provide methods for PCR manufacturers to implement quality test procedures in their facilities. The quality standards enable each company to evaluate and then improve the quality of PCR that they produce. The testing protocol ensures data accuracy and indicates specific testing properties of the PCR that resin suppliers usually choose for quality control purposes to ensure the PCR complies with company standards.

Testing Plan

A testing plan for PCR is a crucial element of the testing protocol that should be a part of every PCR processor. Testing plans are typically set up with references to acceptable quality levels. The testing plan identifies key test procedures, the order in which to run the tests, the method for sampling the plastic materials, and way in which the results are reported. A testing plan provides uniformity in the test methods and standardization for the test results. This helps to provide more consistent results and enables companies to have more reliable data.

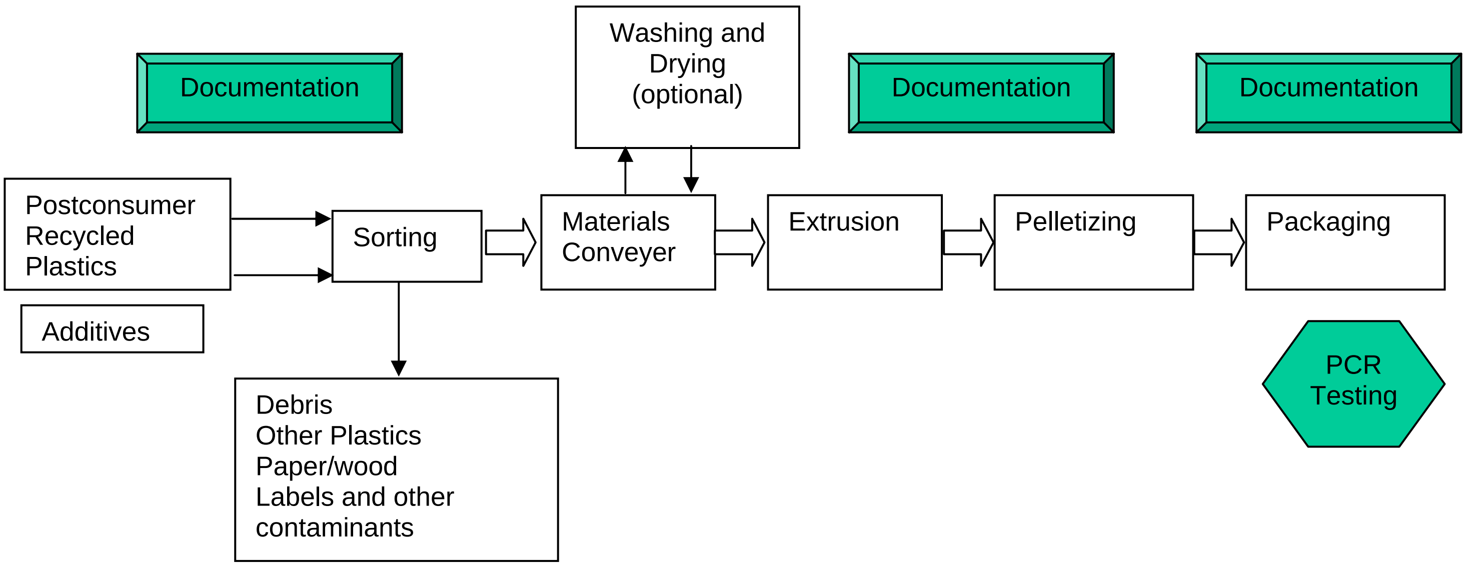
Different testing plans should be established for different types of PCR products from bottle, film, sheet, bags, and others. Each company should take the guidelines that were proposed in this research and include them in their respective quality procedures and quality assurance program. Each company can match the guidelines listed for the grade level of PCR to the type of product they produce. For instance, rigid packaging container manufacturers can take the guidelines for grade levels 4 or 5 and add the quality procedures to their existing quality assurance program.

Similarly, PCR manufacturers who produce PCR that is used in trash bags can take the guidelines for quality grade levels 1, 2, or 3 and then add the quality procedures to their existing quality assurance program. The testing programs from the PCR guidelines for film-grade PCR used in trash bags are based on ASTM standards for melt index, density, moisture, dart strength, and tear strength. The analytical procedures for the tests are described in the ASTM standards.

Laboratory Quality Assurance

The guidelines identify the number of samples required for each test and the frequency of taking PCR samples. The laboratory that is used to test the materials should have sufficient quality assurance built into its procedures by using ASTM standards and procedures when running tests. Also, independent sources are available to certify and validate the laboratory. Documentation of the testing results is crucial in any quality assurance program, and records should be kept for PCR results in a consistent and uniform format.

Figure 1. PCR Quality Documentation and Testing During PCR Manufacturing Process



The quality assurance guidelines are implemented at PCR manufacturing facilities with documentation and testing of the PCR product as it is produced from postconsumer plastic materials. Figure 1 depicts the different times during the PCR manufacturing process when documentation and testing are needed. The guidelines recommend five quality grades of PCR for the material. The PCR manufacturer can choose which PCR material grade to produce. The current PCR standards are consistent with quality grade level 5. The different quality grade levels require different amounts of documentation and testing throughout the manufacturing process. Each of the grade levels requires different amounts of documentation and testing.

Grades 4 and 5 Testing Program

Potential Uses: Rigid Packaging and Plastic Lumber Type Applications

The current PCR standards only require the PCR to be certified for postconsumer content. For grade level 5, no additional testing is required for PCR. For grade level 4, the PCR is tested for environmental stress cracking resistance (ESCR) according to ASTM D1693.

Grades 1, 2, and 3 Testing Program

Potential Uses: Trash Bag, Sheet, and Film Applications

The testing program for PCR materials of grade levels 1, 2, and 3 is outlined in the postconsumer pellet specification sheet for outgoing PCR materials. The specification is listed in Appendix A. The testing requirements for the three PCR grade levels are very similar in that they require the same type of tests. The difference between the grades is in the frequency of the testing and the expected variation in the samples. The PCR producer will test the PCR product per the procedures outlined in Table 2. Samples are removed from the outgoing Gaylord box at intervals found in Table 2. The testing results are based on averages of three tests.

PCR used for trash bags is required to use Incoming Materials Specification Sheet 1 and follow testing protocol for PCR grade levels 1, 2, or 3. PCR used for rigid packaging containers must use Incoming Materials Specification Sheet 2 and follow testing guidelines for PCR grade levels 4 or 5. As outlined in PCR grade level 3 guidelines, the LLDPE PCR is tested for melt index per ASTM D1238. All of the PCR was tested for melt index even though some of the materials, including PP, are not required since they will not be used in trash bags. The testing plan, which includes the number of tests that are required, is defined in the PCR grade level specifications. The testing plan is included in Table 2.

Table 2. Postconsumer Pellet Specifications: Grade 3 (Refer to Appendix D for more details)

Test	Method and Conditions	Sample Handling Procedure	Test Frequency	Property Range
Melt Index, I_2	ASTM D1238-88	Remove 200 grams of material from Gaylord box. Follow ASTM test procedures.	Every 5th box or as agreed. Average of three samples	+/- 15 percent within shipment. +/- 30 percent across shipments
Melt Flow Ratio I_{21} / I_2	ASTM D1238 Condition E	Remove 200 grams of material from Gaylord box. Follow ASTM test procedures.	Once per campaign	MFR change pre-extrusion to post-extrusion <10 percent
Resin Specific Gravity	ASTM D792-91 or ASTM 1505	Remove 200 grams of material from Gaylord box. Follow ASTM test procedures.	Every 5th box or as agreed	+/- 1 percent
Moisture level	ASTM D-4019-88	Remove 200 grams of material from Gaylord box. Follow ASTM test procedures.	Every 5th box or as agreed	< 750 ppm
Pellet Uniformity		Remove 200 grams of material from Gaylord box. Count the number of pellets necessary for 1 gram.	Every 5th box or as agreed	+/- 10 percent
Contamination Gels and Debris	ASTM D 3351	Take an extruded sample from the 1 mil by 2 in (min.) test strip Gel count and gel types.	Every 5th box or as agreed	The acceptable number and sizes of gels are listed in the specifications for quality grades 1, 2, and 3.
Dart Strength	ASTM D 1709-91	Use extruded sample from above test strip. Follow ASTM procedure.	Once per lot or every 12 hours	As mutually agreed

Test Methods

The analytical procedures for the recommended test methods include use of recording a moving average for the materials so that the quality of the plastic can be tracked for incoming materials, during processing, and for outgoing materials. Key quality characteristics can be plotted versus hours in the day to track the quality over time as the different materials are selected from different lots.

Melt Index

The melt index is an indication of the viscosity of the material. Viscosity is defined as a materials resistance to flow. Thus, the plastic material with a high melt index indicates a material with high flow. Likewise, a plastic material that has a low melt index reflects a plastic that is very viscous and does not flow very much. In the melt index test, plastic pellets are added to a heated chamber.

The pellets then flow through a tubular die as a weighted plunge at the top of the cylinder pushes the plastic through the die at the bottom of the cylinder.

The melt index, with units g/10-min, is recorded for materials based on plastic flow during a 10-minute time interval at a prescribed temperature and mass of plunger.[40] The procedure for running the test is detailed in ASTM D1238.[41] For instance, the melt index test for polyethylene is tested at 190°C with a 2.16 kg plunger load. LLDPE and LDPE were also tested at 190°C with 2.16 kg load. PS and PP were tested at 200°C and 230°C, respectively, with a 2.16 kg load. The melt index tests were performed using Model 1000 from Tinus Olsen Company.

Specific Gravity and Density

Specific gravity is a material property that is very important in determining the quality of the PCR plastic. The specific gravity is the ratio of the materials density to that of deionized water at 23°C. Density is the mass per unit volume of a material. Several methods can be used to measure the density of a plastic material. One method, ASTM D792, involves weighing the plastic sample in air and then in water as it is submerged. The density is the ratio of the two, since the mass of the sample while submerged in water is equal to the volume of water displaced by the material.

Since polyethylene and polypropylene have a density less than 1.0, they will float in water unless a sinker and wire are used to hold the specimen completely submerged as required in ASTM D792. Another method uses a titanium cage to hold the plastic submerged in water. [42] A third method determined the densities of various polyethylene samples using the gradient column technique and checked with a Micrometrics model 1305 gas pycnometer.[43] An aqueous gradient solution of NaBr was used in the gradient column with increments of 0.10 g/cc. In the gradient method, the gradient solution has different densities due to the different concentrations of NaBr and water. The plastic is dropped in the column and sinks to a level that equals its density. The more it sinks, the higher the density of the plastic.

The methods are inexpensive and accurate ways to measure the density of plastic materials. In this research, we used a method similar to the gradient method to measure the density. In the CIWMB testing the density is measured by float/sink method of the plastic in a solution of rubbing alcohol and water. Water has a density of 1 g/cc at 23°C and rubbing alcohol has a density of 0.878 g/cc at 23°C. Rubbing alcohol is available in combinations of isopropyl alcohol and water at different concentrations of alcohol; for example, 50 percent, 70 percent, and 90 percent. Rubbing alcohol from Swans Manufacturing of Smyrna, Tennessee, was used in this experiment and had a 70 percent concentration of isopropyl alcohol and a density of 0.878 g/cc.[44]

Alternative Test Procedures

In addition to the tests outlined in the PCR guidelines, alternative test procedures can be used to better identify causes of quality problems. The tests include differential scanning calorimetry (DSC), Fourier transform infrared spectroscopy (FTIR), and thermogravimetric analysis (TGA). The test methods are described in more detail in the following section.

Differential Scanning Calorimetry (DSC)

Differential Scanning Calorimetry (DSC) is a well-known test that is typically used to determine the thermal properties of plastics, including glass transition temperature, melting temperature, heat of fusion, and specific heat.[45] In this test method a small sample is placed in a small chamber that is heated at a constant rate. The energy in the chamber is measured as the sample is heated.

If the sample undergoes a phase change, as during melting, the amount of energy in the chamber changes. The change in energy is recorded and identifies the glass transition temperature and melting temperature. Every plastic has a melting temperature and a glass transition temperature. The melting temperature and glass transition temperature are affected by plastic type, plastic grade, crystallinity percentage, processing conditions, and thermal history. DSC can be used in conjunction with FTIR to better identify plastics that have similar melting temperatures.[46]

FTIR can identify the chemical structure of the plastic and the DSC identifies the melting point. DSC can also test for levels of antioxidants by using an oxidation induction time (OIT) analysis.[47] Typically, induction time is measured with a DSC by heating the sample in pure oxygen at constant temperature until the antioxidant is entirely consumed. This point is marked by an exothermic reaction from the onset of polymer oxidation. The time required to consume the antioxidant is the OIT.

As polymers are degraded by repeated thermal histories, the amount of antioxidant is decreased and the OIT shortens. DSC can be used in PCR materials to characterize the melting characteristics and indicate the presence of contaminant and the degree of thermal degradation. If the melting range is broad, it is an indication of smaller chain segments that could be a result of thermal degradation. Also, if some of the material melts at a lower or higher temperature than what is known for the PCR, then it would indicate a contaminant material in the PCR sample.

Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared spectroscopy (FTIR) is a test that is used to identify plastic materials. A plastic sample in the form of a thin film or sheet is placed into a chamber that allows a light beam to pass through it. The light beam is varied from low frequency to high frequency and the resulting reflectance is recorded. FTIR is an excellent tool for identification and classification of different types of polymers and provides quantitative information about additives in plastics. The FTIR technique can provide information on chemical structure and requires a small amount of material.

FTIR works very well for most plastics that are clear or light colored. The FTIR technique has some difficulties if the sample is dark or has fillers in them.[42] FTIR also can have difficulty identifying different type of plastics that are in the same plastic family; for example, Nylon 6 and Nylon 6/6. As mentioned earlier, FTIR combined with DSC can be used to distinguish between similar materials like Nylon 6 and Nylon 6/6. FTIR can be used with recycled plastics to identify polymer contaminants like PVC and HDPE and PP for LLDPE. In that case, the FTIR analysis for the LLDPE sample can be compared to a known FTIR spectra for LLDPE and the polymer contaminant can be identified from the deviations in the FTIR spectra.

Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) is a technique that is used to identify microscopic characteristics of polymers and fillers. Scanning electron microscopy (SEM) is a method for high-resolution imaging of surfaces. The SEM uses electrons for imaging, much as a light microscope uses visible light. The advantages of SEM over light microscopy include greater magnification (up to 100,000X) and much greater depth of field.[48] SEM techniques have been routinely used for characterizing the polymer morphology and the investigation of fractured surfaces.[49] SEM can be used to identify adhesion between polymers and reinforcements or filler additives.

Thermogravimetric Analysis (TGA)

Thermogravimetric Analysis (TGA) is a test that is used to quantitatively determine the percentage of glass fiber, carbon fiber, or filler.[50] In this method a plastic sample is heated in an oven from room temperature until all of the polymer sample is burned off. The residue is composed primarily of filler or fiber. The mass of the sample is monitored as it is subjected to an increasing temperature. The resultant thermal curves show the weight loss of the material, measured in weight percentage, and the temperature at which the material ignited. The temperature curves indicate the temperature at which substances ignite and give an indication of the material type. TGA is a very useful method for determining amounts of contaminants in recycled plastics.

X-Ray Fluorescence (XRF)

X-ray fluorescence (XRF) is an excellent analytical tool for the analysis of plastics with additives that contain phosphorous. XRF is an elemental analysis technique with unique capabilities that features high accuracy for major elements. High energy photons (x-rays) displace inner shell electrons. Outer shell electrons then fall into the vacancy left by the displaced electron. In doing so, they normally emit light equivalent to the energy difference between the two states.

Since each element has electrons with more or less unique energy levels, the wavelength of light emitted is characteristic of the element. And the intensity of light emitted is proportional to the elements concentration.[51] Most XRF instruments are capable of scanning through several elements, so in addition to phosphorous, sulfur and other metals may also be analyzed. For example, XRF can be very helpful in identifying calcium in an additive that has calcium stearate, a common mold release. XRF is also used for determining amounts of antioxidants in plastics, since antioxidants are blended with phosphorous-containing secondary stabilizers.[52]

Cost of Testing

The cost of testing depends on the materials, equipment, and procedures that are required. The cost can be minimized by following the ASTM procedures, proper training of personnel, and by ensuring that an independent laboratory certifies the equipment periodically. The sampling plans for handling the postconsumer incoming plastics and the outgoing PCR product are detailed along with the testing procedures in the incoming material specification sheet and the PCR quality-testing sheet.

The testing methods are based on the ASTM standards, where available. The experimental results clearly demonstrate that the testing methods are consistent, practical, and valid since they are based on ASTM methods and use statistics in the formulation of the data. Further testing could be done to verify that the results are reproducible by running the tests at another test facility and comparing the data. The tests are economically feasible since they are run on relatively inexpensive test equipment.

Table 3. Typical Costs of Test Equipment for Quality Assurance Laboratory

Equipment	Cost	Company	Phone number	Source
Melt Index	$10,000	BT TECHNOLOGY	(217) 322-3768	www.bttechnology.com/
Density	$11,000	BT TECHNOLOGY	(217) 322-3768	www.bttechnology.com/
Stress Crack ESCR Equipment	$15,000	BT TECHNOLOGY	(217) 322-3768	www.bttechnology.com/
DSC	$30,000 used $60,000 new	Perkin Elmer	(888) 781-0328	www.labx.com/
FTIR	$35,000 used	Nicolet	(888) 781-0328	www.labx.com/
TGA	$12,000 used $67,000 new	TA Instruments	(888) 781-0328	www.labx.com/
XRF	$30,000 used $7,500 used	Siemens SRS303 Equipment	(888) 781-0328	www.labx.com/
SEM	$95,000	Hitachi	(888) 781-0328	www.labx.com/
Extruder 1" Processing Equipment	$10,000	Texas Extrusion Service	(281) 350-2288	www.texasextrusion.com/TESSite1/used.htm

The testing that is required for quality assurance can also be performed at a contract company. Two companies in California that can provide quality type tests are CRT Laboratories at (714) 283-2032 in Orange County, California (for melt index, density, DSC, FTIR); and OCM Test Laboratories at (714) 630-3003 in Anaheim, California (for TGA, density).[53]

Costs for hiring a company to run the tests must be weighed against the costs of purchasing the test equipment. The costs for melt index and density testing are approximately $135 and $65 per material, whereas the costs for DSC and FTIR and TGA are approximately $165 per material. The independent testing source can also be used for quality audits of the company's testing lab. PCR samples can be tested at least once a year at an independent testing source, and their results compared with test results from the company's test lab.

The test equipment that is required to perform quality tests at each PCR company depends on the testing needs. The cost of performing the quality tests is related to several factors, including cost of equipment, number of tests required, time required to run each test, and the salaries of the testing personnel. The cost of quality testing can be minimized by requiring the minimum number of tests with the minimum frequency of tests on the least expensive equipment. The tests required for each quality grade level of PCR are listed in Appendix B. The cost of the test equipment is provided in the Table 3. The costs are representative numbers and reflect values that were available at the listed website. The equipment that is listed is either used or new, which is reflective in the cost.

Step 5. Evaluation of PCR Guidelines

The testing protocol and PCR guidelines were adapted to fit within the quality procedures of three PCR manufacturing companies in California. The procedures that the operator uses to implement the quality plan are included in the quality manual. The quality manual is comprised of quality procedures that describe the way in which an operator performs his production tasks. The manual includes quality control sheets for incoming materials, process conditions, and final PCR product.

The key features of the quality control procedures are the use of a “Production Control Sheet” (Appendix G) that accompanies every Gaylord box of PCR, a “Production Operations Sheet” (Appendix H) that records the processing information for the daily production, a “Production Set-Up Sheet” (Appendix I) that identifies the production conditions for a particular customer, and Contaminated Material Notification (Appendix J) for quality control of incoming recycled plastic. Only the first sheet, the production control sheet, requires information to be added by the operator.

The information includes items necessary to identify the Gaylord box contents (weight, material type, customer name, etc.), quality inspection of incoming materials, and tests required for quality assurance. The production manager fills out the information for the production set-up sheet based on established successful production parameters and leaves the sheet near the extruder as a daily log. That way the production manager can monitor the production run during the day and evaluate the operation of the extruder and relate it to lot numbers assigned to each Gaylord.

Standard Operation Quality Procedures

During the production operation, the operator will check that the settings on the machines match the established parameters provided on the production set-up sheet. The operator will note on the production control sheet if any parameters are out of specification and the action that was taken. The operator will also complete contaminated material notification if the incoming recycled material fails to meet the quality standards listed on the production control sheet.

The modified PCR guidelines were effective in capturing the important quality parameters during the production of PCR at the PPP Incorporated and Joe’s Plastic Company near Los Angeles, California. The modified guidelines effectively monitored key production parameters and efficiently recorded the quality information in a short amount of time. The PCR guidelines were adaptable in two different operations and were acceptable to the two production managers. The guidelines provide a way in which the two companies increased their knowledge of quality practices. The companies were able to better appreciate the value that effective quality control procedures have in keeping their process under control.

The modified PCR guidelines can be used with very little capital cost or employee training. Additionally, the modified guidelines can help PCR manufacturers gain a better understanding of how using an effective quality control program can improve their business operation and yield higher profits due to the reduction in scrap and the increase in their production yield. The quality control program based on the modified PCR guidelines can also help improve the quality of the PCR that can result in a higher selling price.

Evaluation of PCR Quality at PCR Manufacturers

The quality control procedures and guidelines and testing protocol were modified and improved to be more effective and efficient. The guidelines and testing protocol were effective in the laboratory environment in the previous phase, but were improved to better capture the quality of PCR in production facilities. The most common method to characterize the PCR is by measuring the melt index and density. Pellet count and the level of contamination are important measures of the quality of PCR and how efficiently PCR can be processed.

Practical and effective tests are needed to measure the quality of PCR in terms of density, melt index, pellet count, and contamination level in the PCR. The objective of the proposed testing standards is to provide methods for PCR manufacturers to implement efficient and effective quality test procedures in their facility. The test standards will enable each company to evaluate and then improve the quality of PCR that they produce. The testing protocol ensures data accuracy and indicates specific testing properties of the PCR that resin suppliers usually choose for quality control purposes to ensure that the PCR complies with regulatory requirements.

Three companies were selected to demonstrate the effectiveness of the PCR guidelines and the testing protocol. The companies were PPP Incorporated, Joe's Plastics Company, and Advanced Recycling Technologies, Incorporated. All three companies are located in California and provide PCR materials for rigid packaging and trash bag producers. The respective quality programs at each company were reviewed, and PCR samples of the plastic product were retrieved for testing at CSU Chico.

In August 2004, the quality guidelines were presented to each company as well as the way in which they could be added to each company's quality control system. In October 2004, the companies were visited again and the PCR guidelines were modified and improved. Advanced Recycling Technologies, Incorporated, filed for bankruptcy in October and was not available for a follow-up visit.

The PCR materials that were taken at two companies were tested at CSU Chico for melt index, density, pellet count, and contamination. The tests were based on test procedures used at Joe's Plastics and those identified in the modified PCR guidelines. The four tests are efficient ways to test the quality of PCR since they are quick and are inexpensive to run. Additionally, some of the plastics that had a lower-than-expected density were tested for melt temperature profile with the DSC.

The DSC tests clarified the material type based on its melt temperature. The tests do not include moisture since the plastic materials were based on polyethylene, polypropylene, and polystyrene, which are all hydrophobic and, as such, do not absorb much water. Moisture testing can be required if the PCR is known to be susceptible to moisture absorption or if the recycled plastic is wet. The materials include samples taken in August 2004 and those taken in October 2004. During those months, the two companies evaluated the quality assurance procedures listed in the quality manual and implemented them as they could in their production operation. The quality of the PCR may also be affected by the availability of recycled plastic materials, the functioning of the manufacturing operations, the skill level of the operators, and how many procedures of the PCR guidelines were adopted.

Case 1. PPP Incorporated

PPP Incorporated is located in Vernon, California. The facility has one large extruder that produces PCR with postconsumer and postindustrial plastics. The recycled plastic pellets are used for bags, sheet, or packaging applications. In their process, the box of recycled plastic is moved by forklift to the base of the conveyer and emptied into the table that feeds the conveyer. The plastic is checked for labels and other debris by visual inspection and the contraband items are removed. The plastic is conveyed up a ramp and into a shredder machine. A metal detector stops the conveyer if any metal pieces are present. An operator has to find and remove the metal before the line can start again.

Once the metal-free plastic reaches the top of the conveyer it falls into the crusher and is ground up to smaller particles and flakes. The crushed material is conveyed to the extruder and additives like colorants, heat stabilizers, antioxidants, virgin resin, etc. are added to the material before it enters the extruder hopper. The plastic and additives are sent to the extruder and then are heated in the barrel and conveyed to the pelletizer at the end of the extruder.

The extruder has 12 heating zones. The die plates have four heating zones, and the head die has three heating zones. The plastic passes through a screen pack before it enters the die. The screen packs collect debris and un-melted plastic that can contaminate the PCR. The screen packs are changed when a pressure alarm sounds; but the pressure is not recorded. The plastic is extruded out and sent into a water bath and cut into small pellets. The pellets are sent to cyclone dryer and then dropped into a Gaylord box for packaging. The quality procedures at the facility included visually inspecting the incoming plastic materials, visually monitoring the extruder temperatures and pressures, and completing a production sheet for the product as it was boxed.

The recycled plastic materials were stored in Gaylord boxes and segregated into two areas, one area for postconsumer plastics and one area for postindustrial plastics. Postconsumer recycled plastic was available from large plastic bags filled with LLDPE stretch wrap that had been used to cover furniture. The box of postconsumer plastic film materials weighed approximately 400 pounds and was added to the sorting table with postindustrial plastic in a ratio of one box of postconsumer to four boxes of postindustrial materials.

Problem Definition

PPP Incorporated did not have a very detailed quality system at its facility and requested help to implement one. The problems that occur at the plant include contaminants from incoming recycled plastic, puffiness of PCR pellets due to moisture, and inconsistent PCR pellets. The following contaminants were identified in the incoming material, namely, printed labels with black ink (less than 1 percent), white paper labels (less than 2 percent), rubber (less than 1 percent), staples or glue (less than 1 percent), and plastic tape (less than 1 percent) which are removed by the operator.

The PCR appeared acceptable for use in rigid packaging applications, and the material has a PCR quality rating of 5. No additives were used in re-stabilization of the PCR. Postconsumer recycled plastics are in limited supply, which causes a problem for producing PCR for PPP Incorporated. The processing parameters during production also contribute to the quality problems in PCR. The machines are rarely monitored in the production operation, and thus very little quality control is recorded. PPP Incorporated only records the production output, the type of plastic, and lot number of the PCR that is produced on a particular date. The quality of the plastic is not measured after it is produced, but evaluated by visual inspection. Also, the processing conditions are not recorded during the production of the plastic.

Classification and Root Cause of the Problem

The Fishbone Diagram can be used to identify causes of quality problems at PPP Incorporated. The diagram lists all of the potential factors that could cause a quality problem. The fishbone methodology separates the problems into five categories including method, material, personnel, equipment, environment, and uncontrollable factors. An additional category was added to include the testing method. The problems associated with the manner by which they produce the PCR plastic are listed on lines below the method category.

Similarly, the factors associated with the other categories are listed below the category. Twenty-seven potential causes of quality problems were identified at PPP. A severity rating is assigned for the problem on how much impact the problem would have on the quality of PCR. The ratings can be high, medium, or low. Also, the likely frequency of the problem occurring at PPP Incorporated is also provided.

The important potential causes of quality problems can easily be identified as having high impact and high frequency. The causes with the high potential for quality problems are (1) the lack of an adequate supply of postconsumer plastic materials, (2) potential contaminants in the incoming recycled plastic, including metal objects, tape, other plastics, paper labels, ink from labels, (3) the use of visual inspection methods to evaluate the incoming plastic materials and outgoing PCR product, and (4) lack of documentation on process parameters as the PCR is produced. Other problems listed can cause quality problems, but are considered less severe than the three mentioned.

A listing of solutions for the quality problems is provided in Appendix F. The PCR material is most affected by the lack of consistent supply of clean PCR. The production manager mentioned several times that his biggest quality concern is the difficulty he has in obtaining quality postconsumer recycled plastic materials. Unfortunately, it is too big a problem to be solved with this PCR quality assurance project. It can only be solved by a comprehensive management plan developed by the California Integrated Waste Management Board with input from the PCR industry. The other causes of PCR quality problems can be solved with the establishment and use of a quality assurance and quality control methods. The contaminants can be removed by better inspection procedures of the incoming recycled plastic material and by better coordination between the PCR manufacturer and the recycled plastic source.

Action Plan

After the causes of quality problems are identified at PPP Incorporated, an action plan is needed to address the problems. As mentioned previously, a significant cause of quality problems at PPP that is beyond the scope of this research is attributed to the lack of suppliers of clean, postconsumer recycled plastic. Three of the four causes of quality problems at PPP Incorporated, though, can be remedied with improvement to the quality procedures at the company.

In fact, if the PCR guidelines were adopted at the company, many of the causes of quality problems can be significantly reduced. The action plan to improve the quality procedures at PPP Incorporated by incorporating a quality program can be broken into the following steps: (1) modify existing quality procedures to include PCR guidelines and testing protocol, (2) implement the quality procedure at the production facility by training the production personnel, (3) test the PCR produced at the facility before and after the new quality program is used, (4) evaluate the quality improvement in the PCR, and (5) modify the quality procedures to be more efficient and effective. The last step should be an ongoing action by the production team to provide continuous improvement to the PCR manufacturing process. The quality guidelines and testing allow continuous improvement activities.

Evaluation of PCR Quality Improvement

The effectiveness of the PCR guidelines can be evaluated by measuring the quality of the PCR produced with the guidelines. The PCR materials were tested at CSU Chico for melt index, density, pellet count, and contamination. The tests are based on procedures used at Joe’s Plastics and those identified in the modified PCR guidelines. The four tests are efficient ways to test the quality of PCR since they are quick tests and are inexpensive to run.

Additionally, some of the plastics that had a lower-than-expected density were tested for melt temperature profile with the Differential Scanning Calorimetry (DSC). The DSC tests clarified the material type based on its melt temperature.

The materials include samples taken in August 2004 and those taken in October 2004. The PCR materials from PPP Incorporated were made from recycled linear low density polyethylene (LLDPE) bags that were used to cover furniture. In August a lot of recycled plastic bag materials were available. The production manager at PPP Incorporated stated the recycled content of the PCR was 20 percent (by weight). The other 80 percent of plastic used to produce the PCR was from various postindustrial plastic bag materials. In October very little recycled material was available. In fact, during the visit, the last box of the recycled plastic bags was used to make the PCR. The PCR material produced on October 21, 2004, was made from 10 percent (by weight) postconsumer plastic (LDPE stretch wrap used to cover new furniture) and 90 percent postindustrial LDPE and LLDPE.

Tests Performed

Melt Index

The melt index is an indication of the viscosity of the material. The procedure for running the test is detailed in ASTM D1238.[54] In the testing, the melt index for polyethylene is measured at 190°C with a 2.16 kg plunger load and a six-minute time interval. Table 1 lists the results of the melt index testing for material taken in August 2004 and October 2004 from PPP Incorporated. The results are averages of three test samples. The standard deviation and coefficient of variation (CV) are also included. The CV is the ratio of the average value to the standard deviation. The CV indicates the variability of the material.

Thus, variation between samples with different average values can be compared. For instance, CV would be very helpful to compare the variation in melt index and the variation in pellet count, which has a much larger mean value. The melt index variation was higher for LLDPE that were produced in October 2004 than similar materials produced in August 2004, though within the specifications in the PCR guidelines of +/- 10 percent.

Specific Gravity and Density

Specific gravity is a material property that is very important in determining the quality of the PCR plastic. In the testing, several plastic cups were filled with different concentrations of rubbing alcohol and water with different densities. The relationship between density and volume percentage of rubbing alcohol is based on the rule of mixtures, which states that the density of a solution of materials is the arithmetic average of the volume percentage of each material's density. The density of the solutions ranged from 0.88 to 0.94 g/cc at an increment of 0.01g/cc.

A plastic material from Eastman Chemical, CV77512X,[55] was used as a control. The plastic has a density of 0.906 g/cc and a melt index of 0.5 g/10 min. Ten plastic pellets of the control plastic were dropped in a solution with density 0.91g/cc, and all 10 pellets floated. Thus, the plastics are lighter than 0.91. Ten other plastic pellets were dropped in a solution with density 0.90 and all 10 pellets sank, indicating a density greater than 1.0. Thus, the density is measured at 0.905 since it is the average of the two densities where sink/float phenomenon occurred.

The density is not uniform for PCR materials, however, since the PCR is produced from recycled plastic materials with a range of densities. Ten plastic pellets were selected from each PCR material type and dropped in a series of cups with a range of densities. The number of pellets that sink is recorded at each density increment. The average density is calculated based on the frequency of pellets that sink at the particular density solution. For example, if all 10 plastic pieces sink at one density and 8 sink at the next higher density increment, then 2 pellets have a density that is an average of the two density increments. The procedure is repeated with 10 new plastic pellets until all 10 pellets float. The method was used to measure the densities of plastics from 0.88 (density of 100 percent Schwab isopropyl alcohol) to 1.0 g/cc (density of water).

Table 2 of Appendix E lists the results of the density testing for samples taken in August 2004 and those taken in October 2004. The PCR material from PPP Incorporated that was produced in October had a lower-than-expected density as well that could be a result of plastic contamination. These results are typical problems that can result when little documentation is used during the production operation that identifies the plastics used during the production operation of PCR. The quality procedures at each of the two facilities should be modified to include more documentation as described in the PCR guidelines.

The variation in the density as measured with the standard deviation and coefficient of variation (CV) are illustrated in the data as depicted in Table 2.The CV is the ratio of the average value and standard deviation. The LLDPE had lower variation than the LLDPE produced in August 2004. The quick and efficient density testing method can help each company monitor the quality of each of the plastic materials that it produces. This can be done during a longer period of time at each of the facilities so that trends in quality assurance can be established and related to the quality of the PCR produced.

Pellet Count Testing

Pellet count is defined as the number of pellets that weighs 1 gram. The number of pellets that are required to weigh 1 gram +/- 0.05 grams are then divided by the actual mass of the pellets to normalize the count to 1.0 gram. The results are provided in Table 2 for samples taken in August 2004 and October 2004 from PPP Incorporated. Most of the samples had similar pellet count. The variation in the pellet count is measured with the standard deviation and coefficient of variation (CV). LLDPE produced at PPP Incorporated in October had lower variation than the LLDPE produced in August. As before with the density testing, the test method for pellet count quality can help each company monitor the quality of each of the plastic materials that it produces. The quality standards from the new PCR guidelines suggest that the variation in pellet count should be less than 10 percent. The pellet count in the LLDPE produced in October met the quality standards, whereas, the LLPE produced in August did not.

Contamination and Impact Testing

The contamination was measured by producing a compression molded disk of the PCR plastic and then testing the plastic disk with a Gardner drop impact machine. The PCR pellets were placed in a heated aluminum mold and then compression molded at 230°C (400°F) and 50 tonnes (55 tons) force. The temperature can be modified to reflect the melting temperature of the PCR plastic. Thus, if any higher melting temperature plastics are in the sample, they can be identified as un-melted contaminants. The disk is then placed in the impact tester, and a 0.5-inch diameter dart with 8-pound weight is dropped onto it at increments of 1 inch. The height and weight of the dart at failure is recorded. The failed disked is visually examined for discolorations and contaminants. This procedure is similar to one used at Joe's Plastics Company.

Table 4 of Appendix E lists the results of the impact testing for samples taken in August 2004 and those taken in October 2004 from PPP Incorporated. The LLDPE produced in October had lower impact strength than the PP produced in August 2004. The LLDPE produced in October also had discolorations in the plastic pellets that could be caused by a contaminant.

The test method can help PCR manufacturers monitor the quality of the PCR plastic on an ongoing basis. This can be done during a longer period of time at each of the facilities so that trends in quality assurance can be established and related to the quality provided by suppliers of recycled plastic and of the effects of processing conditions. Differential Scanning Calorimetry (DSC) can be used to determine the melting point of the plastic and indicate the type of plastic. For LLDPE, the melting temperature was measured at 120°C and is consistent with LLDPE.

There was not a secondary melting temperature, which indicates that there were not any contaminants.

The quality testing shows that the PCR had slight improvements between samples taken in August 2004 and those in October 2004. Clearly, more time is needed by each company to further implement the quality standards outlined in the quality guidelines. The company should continue to monitor the quality by using the quality procedures developed for them and test the quality of the PCR with the tests outlined in this report.

Further testing could be done to verify that the results are reproducible by running the similar tests with the same material sources and also by running similar tests at another test facility. The verification procedures are outlined in the newly developed quality control manual at the facility.

Case 2. Joe’s Plastics Company

Joe’s Plastic Company is located in City of Industry, California. The facility has seven large extruders with 6.5-inch diameter extrusion screws that produce approximately 700 pounds per hour of plastic for each machine. The input materials are postconsumer and postindustrial plastics. The plastic is a combination of these two recycled materials that are blended in recipes to meet the customer’s requirements. The plastic pellets are used for bags, sheet, pipe, or packaging applications. The materials include linear low density polyethylene (LLDPE), high density polyethylene (HDPE), low density polyethylene (LDPE), and polypropylene (PP), Polystyrene (PS), Acrilonitrile butadiene styrene (ABS), polycarbonate (PC), PC/ABS, polyvinyl chloride (PVC), Nylon 6/6, Nylon 6, ethylene vinyl acetate (EVA), and thermoplastic urethane (TPU). PVC is not processed through the extruders, but instead is just ground up and placed in Gaylord boxes.

The recycled plastics were sorted, chopped, and densified in an operation separate from the extrusion line. The chopped materials are placed in a Gaylord box and then moved to a storage area until its time for processing. The recycled plastic is combined with other additives to produce plastic pellets per recipes generated with customers. The extruders also produced custom plastic mud-flaps and roll stock from the recycled plastic pellets.

The plastic pellets are tested for density, melt index, impact, and contamination. The density is measured using a sink/float test in a 30 percent solution of isopropyl alcohol in water which produces a density of 0.96 g/cc. The melt index is measured on a standard melt index machine per ASTM methods. The impact properties and contamination level are measured by preparing a small disk of material with a compression molder and then breaking it in a dart impact test. The fracture surface is inspected for contamination that is represented by a discolored area in the disk. The existing quality control program includes very good documentation for production PCR, contamination notification sheet for incoming materials, and tests for melt index and impact strength.

Problem Definition

Joe’s Plastics has a quality assurance plan that includes testing of the PCR product. PCR was produced from polypropylene automotive bumpers and polystyrene coat hangers. The PCR material produced for us during the visit was made from approximately 10 percent postconsumer plastic and 90 percent postindustrial PS and PP. The following contaminants were noticed in the incoming material, namely, white paper labels (less than 1 percent), rope (less than 1 percent), metal pieces (less than 1 percent), broken wood (less than 1 percent), and plastic tape (less than 1 percent) which were removed by the operator. The manufacturing process at Joe’s Plastics is different from other manufacturing operations in the way they take the recycled plastic and convert it to a ground plastic that is added to a particular extruder.

The recycled plastic is chopped up in a grinder that is cleaned between each material change. The box of chopped plastic is tested for melt index and density and checked for contaminants. The box of chopped recycled plastic is moved to the extruder and mixed with other plastics that have similar melt index and density in a recipe at the extruder. That way the melt index and density of the PCR product can be adjusted based on melt index and density. This technique can be especially helpful for trash bag manufacturers who can blend low-melt index LLDPE PCR with higher melt index LLDPE to produce a PCR with an acceptable melt index. The plastic is added to the extruder in a batch process rather than a continuous process.

Each extruder runs only one type of materials; for example, PP on one extruder, PS on another extruder, and polyethylene on a third extruder. The grinding area, where they chop up the recycled plastic into small pieces, is separate from the compounding area. Thus, several recycled plastic sources can be used in a mixture of recycled plastic for a particular PCR product. The quality of the PCR was moderate and appeared acceptable for use in rigid packaging applications with a PCR quality rating of 5. No additives were used in re-stabilization of the PCR. Joe's Plastics Company has a quality control system that needs more documentation on incoming materials and processing conditions. The company would benefit from combining the PCR guidelines with their own quality control system.

Classification and Root Cause of the Problem

As before, the Fishbone Diagram can be used to identify causes of quality problems at Joe's Plastics. The Fishbone diagram for Joe's Plastic does not include a section for testing method since they have quality control test procedures. The diagram lists all of the potential problems that could cause a quality problem. Twenty-four potential causes of quality problems were identified at Joe's Plastics. The next step in the process is to assign a severity rating for the problem on how much impact the problem would have on the quality of PCR. The ratings can be high, medium, or low.

Also, the likely frequency of the problem occurring at Joe's Plastics is also provided. The important potential causes of quality problems can easily be identified as having high impact and high frequency. Similar to the study for PPP Incorporated, the causes with the high potential for quality problems are (1) the lack of an adequate supply of postconsumer plastic materials, (2) potential contaminants in the incoming recycled plastic, including metal objects, tape, other plastics, paper labels, (3) visual methods to identify when the screen pack needs to be changed, and (4) the use of visual inspection methods to evaluate the incoming plastic materials. A pressure alarm should be added to notify the operator when the pressure exceeds a set value—for example, 2,500 psi—indicating a plugged screen pack. Other problems listed can cause quality problems, but they are considered less severe than the four mentioned.

The root cause of the poor quality is a combination of visual inspection techniques of incoming materials, inadequate documentation of process conditions, and inadequate supply of quality recycled materials. These are identified using problem analysis methods such as the Fishbone Diagram. The most important cause of PCR quality problems is the lack of suppliers that can provide recycled plastic of high quality. The other causes of PCR quality problems can be solved with improving their quality control procedures to include more inspection sheets and to rely less on visual inspection methods.

The contaminants can also be removed by using inspection sheets for incoming recycled plastic material and by requiring the recycled plastic to meet specific quality standards, which are given to the supplier of recycled plastic. They also could improve quality by having an automatic screen pack changer and installing a high-pressure alarm system near the screen pack. The remaining causes of PCR problems can be reduced or eliminated by improving the quality control procedures and increase the training for workers. The PCR is tested to determine if it meets the specifications of the modified PCR guidelines. If the PCR is rejected, it is recycled back into the compounding operation and made into new PCR. The level of rejects is difficult to determine, since all of the rejected material is blended back into the production operation.

Action Plan

After the causes of quality problems are identified at Joe's Plastics, an action plan is needed to address the problems. The problems with the PCR at Joe's Plastics are similar to the causes of quality problems at PPP Incorporated. As mentioned previously, a significant cause of quality problems at Joe's Plastics that is beyond the scope of this research is attributed to the lack of suppliers of clean, postconsumer recycled plastic. Three of the four causes of quality problems at Joe's Plastics, though, can be remedied with improvement to the quality procedures at the company.

The action plan to improve the quality procedures at Joe's Plastics can be broken into the following steps: (1) modify existing quality procedures to include PCR guidelines and testing protocol, (2) implement the quality procedure at the production facility by training the production personnel, (3) test the PCR produced at the facility before and after the new quality program is used, (4) evaluate the quality improvement in the PCR, and (5) modify the quality procedures to be more efficient and effective. The last step should be an ongoing action by the production team to provide continuous improvement to the PCR manufacturing process.

The PCR materials from Joe's Plastics were made from recovered LDPE, PP, and PS. The PCR content was 10 percent for PP and 12 percent for PS. The PP was made from recycled diapers in August 2004 and from recycled bumper covers in October 2004. The PS was produced from coat hangers in October 2004. The quality control manager did not state the sources of the recycled plastics for LDPE.

Evaluation of PCR Quality Improvement

The effectiveness of the PCR guidelines can be evaluated by measuring the quality of the PCR produced with the guidelines. The PCR materials were tested at CSU Chico for melt index, density, pellet count, and contamination. The tests are based on procedures used at Joe's Plastics and those identified in the modified PCR guidelines. The four tests are efficient ways to test the quality of PCR, since they are quick tests and are inexpensive to run.

Additionally, the polystyrene had lower-than-expected density and the polypropylene had higher-than-expected density. They were tested for melt temperature profile with the Differential Scanning Calorimetry (DSC). The DSC tests classified the material type based on its melt temperature. The tests do not include moisture since the plastic materials were based on polyethylene, polypropylene, and polystyrene, which are all hydrophobic and, as such, do not absorb much water. Since moisture can appear in the form of droplets within underwater pelletized materials, the test for moisture should be retained. The materials include samples taken in August 2004 and those taken in October 2004.

Tests Performed

Melt Index

The procedure for running the test is detailed in ASTM D1238.[56] PS and PP were tested at 200°C and 230°C, respectively, with a 2.16 kg load. As before, the melt index tests were performed using Model 1000 from Tinus Olsen Company.

Table 1 in Appendix E lists the results of the melt index testing for samples taken in August 2004 and those taken in October 2004 from Joe's Plastics. The standard deviation and coefficient of variation (CV) are also included. The results demonstrate that PP from October and PS from August produced at Joe's Plastics have the lowest variation. The melt index of materials from Joe's Plastics is higher than the melt index of materials from PPP Incorporated. The materials from Joe's Plastics are most likely produced from injection grade recycled plastic. The variation in melt index is less in some materials (for example, PS) that were produced in October than for those produced in August. However, the melt index variation was higher for PP and LDPE that were produced in October than similar materials produced in August.

Specific Gravity and Density

Specific gravity is a material property that is very important in determining the quality of the PCR plastic. The sink/float method was used to measure the densities of plastics from 0.88 (the density of 100 percent Schwab isopropyl alcohol) to 1.0 g/cc (the density of water). For the polystyrene PCR, a sink/float method was used with a container of water with a density of 1.0 g/cc and a second container of Prestone ethylene glycol with a density of 1.12g/cc.[57] The sink/float procedure in the two containers was used to test the density of PCR of PS in August 2004 and PS in October 2004 made from recycled coat hangers. In the testing none of the PS produced in August sank in pure water and thus has a density of less than 1.0. Most of the PS produced in October sank at 1.0 and all of the PS floated at 1.12 and thus had an average density between 1.0 and 1.2 g/cc. The results are listed in Table 2 of Appendix E.

The results of the density testing from Joe's Plastics note that the density of PP was higher in August 2004 than in October 2004. The PP made in August from diapers may have had some other plastics, that is, LDPE, that would increase the density of the material. This can be tested later with the use of the DSC. The PP made in October from bumpers had very little variation and had a density consistent with PP. This can be attributed to the uniformity of the polypropylene used in bumper covers. The bumper covers are called fascias and are made from a plastic material called thermoplastic olefin (TPO).[58] The TPO is rubber-modified PP.

The PS produced in August 2004 from Joe's Plastics also had a lower-than-expected density. It also might have some other plastic contaminant, for example, PP, LDPE, or HDPE. These results are typical problems that can result when little documentation is used during the production operation that identifies the plastics used during the production operation of PCR. The quality procedures at each of the two facilities should be modified to include more documentation as described in the PCR guidelines.

The variation in the density as measured with the standard deviation and coefficient of variation (CV) are illustrated in the data as depicted in Table 2. Table 2 demonstrates that the PCR-PP from October 2004 and PCR-LDPE from August 2004 have the lowest variation in density. The PCR-LLDPE produced at PPP Incorporated had lower variation than the PCR-LLDPE produced in August.

Similarly, the PP produced at Joe's Plastics Company in October 2004 had less variation than PP produced in August 2004. The variation in density is slightly higher for PS that was produced in October 2004 than those used in August. The results are not surprising since different recycled plastics were used to produce PCR in August than those in October. Thus, the materials are not the same even though they are the similar family type. Also, the processing conditions may be different as well as the equipment used and personnel involved. Thus, the best that can be inferred by the results is that variations in density are strongly dependent on the quality of the incoming plastic materials.

Pellet Count Testing

Table 3 in Appendix E lists the results of the pellet count testing for samples taken in August 2004 and those taken in October 2004 of five PCR plastics from Joe's Plastics. Most of the samples had similar pellet counts, except the PS produced in August at Joe's Plastics. The conditions that produced this small size of pellet are not known due to the lack of information provided by the company.

Table 3 demonstrates that the PP from October 2004 and PS from August 2004 have the lowest variation. The PP produced at Joe's Plastics in October had less variation than PP produced in August. The variation in pellet count is higher for PS that was produced in October than those produced in August. As before with the density testing, the test method for pellet count quality can help each company monitor the quality of each of the plastic materials that it produces. The quality standards from the new PCR guidelines suggest that the variation in pellet count should be less than 10 percent. Most of the samples met the standard except the PS produced at Joe's Plastics in October.

Contamination and Impact Testing

The contamination was measured by producing a compression molded disk of the PCR plastic and then testing the plastic disk with a Gardner drop impact machine. The PCR pellets from PS, PP, and LDPE were placed in a heated aluminum mold and then compression molded at 230°C (400°F) and 55 tonnes (50 tons) force. The height and weight of the dart at failure is recorded. The failed disk is visually examined for discolorations and contaminants. This procedure is similar to one used at Joe's Plastics Company.

Table 4 in Appendix E lists the results of the impact testing for samples taken in August 2004 and those taken in October 2004 of five PCR plastics from Joe's Plastics. The PP produced in October from Joe's Plastic had higher impact strength than the PP produced in August. Similarly, the PS produced in October from Joe's Plastics had higher impact strength than the PS produced in August. Obviously, the material sources were different from the PCR produced at both companies in October as compared to those produced in August. The test method can help PCR manufacturers monitor the quality of the PCR plastic on an ongoing basis. This can be done during a longer period of time at each of the facilities so that trends in quality assurance can be established and related to the quality provided by suppliers of recycled plastic and of the effects of processing conditions.

Differential Scanning Calorimetry (DSC)

The melting temperature of each PCR was measured with a Differential Scanning Calorimeter (DSC) and compared to published values for the plastic material. The results are listed in Table 5 of Appendix E and Appendix J, which demonstrate that the two materials had melt temperatures consistent with published values. PP and PS had values that were consistent with published values. However, the DSC curve for PS produced in August 2004 at Joe's Plastics demonstrates a secondary higher melting point material, possibly PP, which might be a contaminant. Likewise, the DSC curve for PP produced in August 2004 at Joe's Plastics demonstrates a lower melting point material, possibly LDPE, which might be a contaminant.

The addition of PP to the PS would provide an explanation of the low density of the PS. The addition of LDPE to PP would explain the high density for the PP. The contaminants can be further identified with other tests. For example, Fourier Transform Infrared Spectroscopy (FTIR), or Thermogravimetric Analysis (TGA), could determine the amount and type of contaminant.

The quality testing shows that the PCR had slight improvements between samples taken in August 2004 and those in October 2004. Clearly more time is needed by each company to further implement the quality standards outlined in the quality guidelines and to continuously monitor the quality of the PCR.

Conclusions

The proposed PCR guidelines and testing protocol are effective and efficient ways to improve the quality of PCR. Typically, the large PCR manufacturers have quality assurance programs in place that monitor the quality of PCR as it is produced. The guidelines and testing protocol can be added to their existing quality control procedures. Alternatively, the small PCR manufacturers do not have quality control procedures defined at the company and rely on visual inspection methods for incoming recycled plastic and outgoing PCR product.

The companies should develop their own quality control procedures from the proposed PCR guidelines and testing protocol. The proposed testing protocol is efficient since it relies on inexpensive but effective test methods, which requires minimal operator training, limited number of tests, and relatively inexpensive equipment. The proposed PCR guidelines and testing protocol can help both large and small PCR manufacturers improve the quality of the PCR that they produce.

The PCR guidelines were evaluated with PCR materials produced at two production facilities. The guidelines were evaluated based on their adaptability to quality procedures at the production facilities as well as the resulting quality of PCR. The PCR was tested for quality based on three efficient and effective tests that are described in the modified PCR guidelines.

The quality of PCR can be affected by many factors, including a lack of quality procedures, documentation, and quality testing at PCR producers, reliance on visual evaluations of incoming recycled plastic and outgoing PCR products, and a lack of available postconsumer material that can be converted into PCR. Problem analysis of the operations at two PCR production facilities in California established that the root cause of PCR quality problems is incomplete quality control in the production operations. As demonstrated at the two PCR processing facilities in California, quality procedures can be improved by incorporating the proposed PCR guidelines.

The testing protocol suggested that PCR had slightly improved after being incorporated in the quality procedures at the two companies. The results showed slightly improved quality at both companies, though more time is needed for each company to improve their quality procedures. An important result is the fact that the companies found the quality standards useful and felt it was important to use quality control procedures at their company.

They also made many important suggestions that are included in the PCR guidelines. The quality tests were useful and required minimal investment costs due to low capital investments and fast testing time. Efficient and effective test methods have been demonstrated that can be easily implemented in PCR facilities with minimal expense. In the research study, the testing methods are based on combinations of ASTM methods and common industrial methods.

The most important factor that can improve the PCR quality is to have a production organization that values and incorporates quality control procedures into its production operations. Successful companies throughout the plastics industry recognize the importance of improving the quality of the product by employing quality control methods that are implemented with minimal costs and with minimum disruption to the current production operation.

The improvement in quality can also increase the value of the product and result in either a higher selling price or reduced downtime and scrap. The scrap rate production in PCR is very low, since most of the material that is out of specification is blended back into the PCR product and not thrown away. However, the cost of time associated with reworking the plastic results in a lower production yield.

PCR can have a higher value if effective quality assurance programs are implemented in processing facilities. If the PCR is certified with a quality grade of 3 or 4 it could warrant a higher selling price versus the current PCR product with a quality grade of 5. The PCR produced at the two companies can be used for rigid applications. This PCR would not be acceptable for plastic trash bag applications due to the dark color and the lack of testing for gels as required in quality level 3 of the PCR guidelines.

The PCR guidelines and testing protocol can be used as a basis for film processors and PCR producers to establish specific specifications for a particular product. The film processor and PCR manufacturer must agree on the quality control values that are suggested in the guidelines. The PCR quality guidelines and testing protocol do not guarantee that a PCR material can be used for commercial products, as this must be agreed to by the companies involved in the contractual relationship.

Recommendations

Obviously, more work is needed to improve the quality of PCR for rigid packaging and trash bag applications. One of the biggest causes of quality problems with PCR is the lack of detailed quality procedures at production facilities. To address this problem the proposed guidelines and testing protocol can be used as a model quality assurance program for PCR in California, the United States, and throughout the world, since very little research publications exist for PCR.

In conclusion, additional training in quality control procedures for PCR manufacturing would be helpful to the industry. Therefore, the Board should work with PCR manufacturers on a voluntary basis to help them modify their own quality procedures using PCR guidelines.

Appendices

Appendix A: Abbreviations for Some Common Plastic Resins

Polyethylene Terepthalate (PETE or PET)

High Density Polyethylene (HDPE)

Polyvinyl Chloride (PVC)

Low Density Polyethylene (LDPE)

Polypropylene (PP)

Polystyrene (PS)

Appendix B: Postconsumer Rating Standards for LLDPE, HDPE, LDPE, PP, and PET

Postconsumer Resin Certification indicates that the plastic used in the production of PCR is from postconsumer materials (PCM) per standards provided in the California Integrated Waste Management Board's Recycled Content Trash Bag Program and the Rigid Plastic Packaging Container Program.

Postconsumer Resin Grades certify that PCR material has a particular quality level.

Note: The guidelines can be used as a basis for film processors and PCR producers to establish specific specifications for a particular product. The film processor and PCR manufacturer must agree on the quality control values that are suggested in the guidelines.

Note: The PCR quality guidelines and testing protocol do not guarantee that a PCR material can be used for commercial products, as this must be agreed to by the companies involved in the contractual relationship.

Grade 1: This is near virgin resin quality that features a film with no lensing and no gels larger than 0.010 inches and less than 15 visible gels per square inch.

> **Products**: Acceptable to be used in trash bag applications if agreed to by trash bag manufacturer.
>
> **Quality Assurance Standards:** same as Grade 3

Grade 2: This is a good film quality that can be readily made into blown film, does not have lensing and does not have hard gels that are visible. Also, no soft gels larger than 0.020 inches. No visible flow disturbances. Less than 65 visible gels per square inch.

> **Products**: Acceptable to be used in thicker film and sheet applications if agreed to by plastic sheet or film manufacturer.
>
> **Quality Assurance Standards:** same as Grade 3

Grade 3: This is an acceptable film quality that features a film that can be readily made into blown film, does not have lensing and has gels that are visible, though at a moderate level. The film features no lensing, no hard gels with diameters larger than 0.015 inches, no soft gels larger than 0.032 inches, and no visible flow disturbances. Gel-count numbers and frequencies have maximum values of 65–70 gels per 50,000 square inches. Note: soft gels can be deformed with slight applied pressure.

> **Products**: Acceptable to be used in thicker film and sheet applications if agreed to by plastic sheet or film manufacturer.
>
> **Quality Assurance Standards**
>
> Incoming Material Specifications: per Incoming Spec 1.
>
> Process Control: Process control sheets required on incoming recycled plastic sources.
>
> Quality assurance standard practices to be performed every 10th box when additional plastic materials and additives are added to the recycled plastic.

Testing: The following additional testing certification beyond PCR certification should be conducted:

- Melt Index
- Density
- Melt Flow
- Moisture
- Odor
- Color

Additional inspection and evaluation of hard and soft gels from extruded 1 mil film strip from 100 percent PCR should be conducted.

Grade 4: Uses current PCR specifications from the CIWMB with additional quality testing for environmental stress cracking. It cannot be used for trash bag blown film.

Products: Acceptable to be used in plastic lumber applications if agreed to by plastic product manufacturer.

Acceptable to be used in rigid packaging containers with testing for environmental stress cracking.

Not acceptable to used in trash bag applications. It cannot be used for trash bag blown film because it features a film that has no lensing and a high number of gels making the appearance unacceptable. The film has no hard gels larger than 0.00015 inches and no soft gels more than 0.032 inches. Gels have slight visible flow disturbances.

Quality Assurance Standards

Incoming Material Specifications: per Incoming Spec 2.

Process Control: None required.

Testing: Testing required for environmental stress cracking resistance plus PCR certification.

Grade 5. This grade can be used for low quality applications and other plastic products but may not be appropriate for food containers. The film has poor quality and features a film that has lensing, gels more than 0.032 inches, and visible flow disturbances around the gel.

Products: Acceptable to be used in plastic lumber applications.

Acceptable for some rigid packaging containers that are not used for oil-based materials.

Not acceptable to be used in trash bag applications.

Quality Assurance Standards

Incoming Material Specifications: per Incoming Specification 2.

Process Control: None required.

Testing: Testing required for environmental stress cracking resistance.

Appendix C: Quality Control Sheets for Incoming Postconsumer Recycled Material

Incoming Material Specifications—Level 1

The incoming recycled plastic materials must meet the following specifications:

Source: Stretch film or equivalent from industrial or commercial collection programs.

Resin: Film Grade LLDPE.

Product: Stretch polyethylene natural film.

Type: Industrial or commercial stretch films and stretch bags.

Bale Properties:

- Dimensions: 2' x 3' x 3' minimum to 3' x 4' x 5' maximum.
- Bale Weight: 1,200 lbs. maximum.
- Strapping: Non-rusting wire or polypropylene.
- Bale integrity: Must be maintained through shipping, unloading, and storage.

Melt Index: Between 0.5–2.5 g/10 min.

Film Density: Between 0.917 and 0.922 g/cc.

Storage Conditions: Bales must be stackable.

Contamination:

- No hazardous materials.
- No medical wastes or sharp objects.
- No animal parts.
- No biodegradable materials.
- No PVC or PVDC.
- No excessive trash, loose paper, or corrugated inside of bale.
- No wood or broken pallets.
- No polystyrene or polyurethane foam.
- No foam plastics.
- No oil or grease.
- Less than 3 percent HDPE film.
- Limited amount of moisture.

- No heavy metals.
- No TNPP antioxidant.

Incoming Material Specifications—Level 2

The incoming recycled plastic materials must meet the following specifications:

Source: Plastic from industrial or commercial collection programs.

Resin: PET, HDPE, film grade LLDPE. LDPE, PP, or PS.

Product: Various.

Type: Industrial or Commercial plastic.

Bale Properties:

- Dimensions: 2' x 3' x 3' minimum to 3' x 4' x 5' maximum.
- Bale Weight: 1,200 lbs. maximum.
- Strapping: Non-rusting wire or polypropylene.

Bale integrity: Must be maintained through shipping, unloading, and storage.

Bale density should not be too tightly packed as defined by the customer.

Storage Conditions: Bales must be stackable.

Contamination:

- No hazardous materials.
- No medical wastes or sharp objects.
- No animal parts.
- No biodegradable materials.
- No PVC or PVDC.
- No amount of trash, loose paper, or corrugated cardboard inside of bale greater than 5 percent of bale or as defined by customer.
- No wood or broken pallets.
- No polystyrene or polyurethane foam.
- No oil or grease present in bale.

Appendix D: Postconsumer Pellet Specifications: Grades 1, 2, and 3

Test	Method and Conditions	Acceptable Values	Typical Test Frequency	Property Range
Melt Index, I_2	ASTM D1238-88	HDPE base resin—0.25–0.85 LDPE base resin—0.25–2.5 LLDPE base resin—0.5–2.5 LLDPE base resin—0.15–0.3 (Fractional melt if agreed to by trash bag and resin manufacturers)	Every 5th Box or as agreed	+/- 15 percent within shipment +/- 30 percent across shipments
Melt Flow Ratio I_1 / I_2	ASTM D1238 Condition E	12–32 45–50 (Fractional melt if agreed to by trash bag and resin manufacturers)	Once per campaign	MFR change pre-extrusion to post-extrusion <10 percent
Resin Specific Gravity	ASTM D792-91 or ASTM 1505-90	HDPE, LDPE, or LLDPE agreed to by trash bag and resin manufacturers	Every 5th Box or as agreed	+/- 1 percent
Bulk Density		> 31.5 lbs/ft^3	Every Hour	32-40 lbs/ ft^3
Moisture Level	ASTM D-4019-88	<750 ppm or 0.075 percent	Every 5th box or as agreed	< 750 ppm
Pellet Uniformity		Number of pellets in 1 gram sample. 5 reps per test	Every 5th Box or as agreed	+/- 10 percent
Contamination Gels and Debris	ASTM D 3351	Extrude a film strip from 100 percent PCM at 1.0 mils & at least 2 in wide. Compare visually against standards.	Every 5th Box or as agreed	Grade 1, 2, 3 are acceptable
Melt Temperature		Measured at repro extruder	Every hour by lot number	
Color	Color Scale L a (absolute) b (absolute)	As mutually agreed > 60 in clear glass cup. < |4| < |7|	Average 5 readings Every 5th box or as agreed	As mutually agreed
Antioxidant Level	TBD	As requested per application		
Wood Contaminant	TGA	< 0.2 percent by weight	Every 5th box or as agreed	
Dart Strength	ASTM D 1709-91	As requested per application	Once per lot or every 12 hours	As mutually agreed
Tear Strength	ASTM D 1922-89	As requested per application	Once per lot or every 12 hours	As mutually agreed

Appendix E. PCR Quality Testing at Joe's Plastics and PPP Incorporated

Table 1. Melt Index

Company/Material	PCR Content, percent	Color	Average Melt Index	Standard Deviation Melt Index	Coefficient of Variation Melt Index
Joe's Plastic					
PP, Aug. 2004—diapers	10	Green	8.124	0.200	0.025
PP, Oct 2004—bumpers	10	Black	2.291	0.155	0.068
PS, Aug 2004	10	Black	0.449	0.178	0.397
PS, Oct. 2004 (12 percent PCM)	12	Black	5.647	0.129	0.023
LDPE, Aug 2004	10	Light Gray	8.083	0.797	0.099
PPP					
LLDPE, Aug 2004	10	Black	0.477	0.023	0.049
LLDPE, Oct 2004	10	Black	0.633	0.053	0.084

Table 2. Density

Company/Material	Average Density	Standard Deviation Density	Coefficient of Variation Density
Joe's Plastic			
PP, Aug. 2004—diapers	0.955	0.042	0.044
PP, Oct. 2004—bumpers	0.891	0.008	0.009
PS, Aug. 2004	0.955	0.042	0.044
PS, Oct. 2004 (12 percent PCM)	1.028	0.066	0.064
LDPE, Aug. 2004	0.905	0.000	0.000
PPP			
LLDPE, Aug. 2004	0.919	0.019	0.021
LLDPE, Oct. 2004	0.890	0.014	0.016

Table 3. Pellet Count (Number of pellets per 1 gram)

Company/Material	Average Pellet Count	Standard Deviation Pellet Count	Coefficient of Variation Pellet Count
Joe's Plastics			
PP, Aug. 2004—diapers	22.580	0.844	0.037
PP, Oct. 2004—bumpers	28.620	0.444	0.016
PS, Aug. 2004	108.600	1.140	0.010
PS, Oct. 2004 (12 percent PCM)	28.380	3.179	0.112
LDPE, Aug. 2004	38.220	2.118	0.055
PPP			
LLDPE, Aug. 2004	41.600	14.391	0.346
LLDPE. Oct. 2004	39.840	1.124	0.028

Table 4. Contamination and Impact Properties

Company/Material	Impact	Contamination
Joe's Plastics	**In lbs**	
PP, Oct. 2004—bumpers	**72**	None
PP, Aug. 2004—diapers	**32**	None
PS, Oct. 2004 (12 percent PCM)	**64**	None
PS, Aug. 2004	**64**	None
LDPE, Aug. 2004	**16**	None
PPP		
LLDPE, Aug. 2004	**144**	None
LLDPE, Oct. 2004	**96**	Some discolored plastic

Table 5. DSC Results

Company/Material	Primary Tmelt °C	Secondary Tmelt°C
Joe's Plastics		
PP, Aug. 2004—diapers	165	125
PS, Aug. 2004	100	175
PPP		

LLDPE, Oct. 2004	120	none

Appendix F. Problem Analysis Table for PPP Incorporated

Problem for PPP Incorporated	Impact	Frequency (H, M, L)	Causes	Solutions
Method				
Lack of documented quality control	M	H	No quality assurance method	Create quality documents
Incoming materials visually inspected	H	H	No quality assurance method	Inspect to checklist
Incoming materials are not tracked for outgoing PCR product	L	H	No quality assurance method	Document quality as PCR is produced
Processing conditions are not tracked for outgoing PCR product	L	H	No quality assurance method	Track processing conditions per lot number
PCR product not consistently tested	M	H	No quality assurance method	Test PCR on regular basis
Material				
Lack of suppliers for postconsumer materials	H	H	Poor coordination from State agencies	CIWMB future study
Incoming material has moisture during rainy season	H	M	Shipping procedures	Inspect to checklist
Contaminants with incoming materials; for example, labels, ink, paper, metal, wood, plastic straps, tape	H	H	Part of postconsumer use	Inspect to checklist
Equipment				
Temperature is too hot on heating zones	M	M	Machine Maintenance	Track processing conditions per lot number
Plastic is not washed in wash line	L	M	Too expensive	Create wash line
Screen packs trap metal and debris often	M	H	Plastic has contaminants	Reduce debris
Process parameters are inspected only if alarm is heard	L	M	High pressures at screen packs	Track processing conditions per lot number
Metal is found with magnets on incoming material and stops the machine	H	M	Dirty incoming plastic	Inspect to checklist
Environment				

Problem for PPP Incorporated	Impact	Frequency (H, M, L)	Causes	Solutions
Humidity problems during rainy season	M	M	Part of weather	Dry material; ship in closed containers
High temperature problems in shop during summer	L	L	Part of weather	Track processing conditions per lot number
Dust problems in shop causing dirt in plastic.	L	L	Broken ventilation	Clean shop regularly
Dirt and debris on floor can get into plastic.	L	L	Plastic falls on floor and is picked up	Clean shop regularly
Personnel				
Workers are not properly trained in plastic materials, safety, quality, and visual inspection procedures.	M	M	Inadequate training procedures	Establish training programs
Workers do not remove contaminants, labels, and tape from incoming plastic.	M	M	Inadequate training procedures	Establish training programs
Workers do not monitor the machine enough and temperatures and pressures get too high and screen pack gets plugged.	M	M	Inadequate training procedures	Establish training programs
English is not the first language of the workers which causes communication problems.	L	L	Workers come from non-English speaking areas	Establish training programs
Testing Method				
No quality tests are required in quality assurance plan.	H	L	No quality assurance method	Require tests
The quality values are estimated for density and melt index based on knowledge.	M	L	No quality assurance method	Require tests
Uncontrollable factors				
The price of recycled materials is high due to China and plastic lumber demands.	M	M	Market forces	CIWMB future study
The price of virgin plastic is close to the selling price of PCR.	M	M	Market forces	CIWMB future study
It is very difficult to find suppliers of recycled materials.	H	H	Poor coordination from State agencies	CIWMB future study

Appendix G. Production Control Sheet

<Company Name and Address and Phone Number>

Box No: ____________ Date: ____________ Time: _________ Operator: _________ Net Weight: _____________

Customer: _________________ Source: _________________

Material Type: ______________ PCR Quality Grade Level: __________Color: _________________

(Add values where appropriate)

Melt: _____________ Density: _____________ Pellet Count: ________ Contamination: _________

Izod: __________ Dart: ____________ Odor ________

(For Rigid Packaging Testing) ESCR: _____________(For Trash Bag Testing) Number Gels per strip: _______________

Incoming Plastic Materials Inspection Sheet (2 boxes of recycled plastic)					
		Box 1,2			Box 1,2
1. Paper Labels	□□	Explain(Approx. percent) _______	2.Ink Labels	□□	Explain(Approx. percent) ________
3. Tape	□□	Explain(Approx. percent) ________	4. Metal pieces	□□	Explain(Approx. percent) ________
5. Foreign plastic pieces	□□	Explain(Approx. percent) ________	6. HDPE or other plastic film	□□	Explain(Approx. percent) ________
7. Moisture	□□	Explain(Approx. percent) ________	8. Broken wood or debris	□□	Explain(Approx. percent) ________
9. PU or foam plastics	□□	Explain(Approx. percent) ________	10. Other	□□	Explain(Approx. percent) ________
Incoming Plastic Materials Inspection Sheet (2 boxes of recycled plastic					
		Box 1,2			Box 1,2
1. Paper Labels	□□	Explain(Approx. percent) _______	2.Ink Labels	□□	Explain(Approx. percent) ________
3. Tape	□□	Explain(Approx. percent) ________	4. Metal pieces	□□	Explain(Approx. percent) ________
5. Foreign plastic pieces	□□	Explain(Approx. percent) ________	6. HDPE or other plastic film	□□	Explain(Approx. percent) ________
7. Moisture	□□	Explain(Approx. percent) ________	8. Broken wood or debris	□□	Explain(Approx. percent) ________
9. PU or foam plastics	□□	Explain(Approx. percent) ________	10. Other	□□	Explain(Approx. percent) ________

Note: The four check squares are for the four Gaylord boxes of recycled plastic that are needed per box of PCR product. Place a check in the square if contaminants are found in the box.

Comments:____

____

____

Appendix H. Production Operations Sheet

<Company Name and Address and Phone Number>

	Box Lot No	Melt Temp OK?	Die Temp OK?	Press OK?	Screw OK?	Screen changes per Hr	Additives Type & amount	Date	Time	Initials
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										

Appendix I. Production Set-up Sheet

<Company Name and Address and Phone Number>

Customer: __________________ Date: _____________ Time: __________

	Parameter	Setting	Max	Min	Comments		Parameter	Setting	Max	Min	Comments
1	Temp 1					1	Temp 10				
2	Temp 2					2	Temp 11				
3	Temp 3					3	Temp 12				
4	Temp 4					4	Press 1				
5	Temp 5					5	Press 2				
6	Temp 6					6	Press 3				
8	Temp 7					8	Press 4				
9	Temp 8					9	Screw Speed				
10	Temp 9					10	Screw Amps				

Additives Required: Antioxidant: __________________Other: ________________________________

Tests Required:

	Parameter	Setting	Max	Min	Comments
1	Melt Index				
2	Density				
3	Gels on Strip				
4	ESCR				
5	Impact				

Appendix I. Contaminated Material Notification

<Company Name and Address and Phone Number>

Customer: _________________ Contact: __________________ Date: ____________ Time: __________

Fax Number: _______________ Phone Number: _____________ Purchase Order Number: ___________

Material Purchased:

____

____

____

Purchased Quantity:

____

Contamination Source:

____

____

____

Contamination Quantity:

____

____

____

Note: Contaminated material will be held for 14 days. Unclaimed material will be discarded. Contaminated material will be deducted from customer invoice.

Note: FAX your reply Instructions Immediately to: (Company Phone Number)
Attention:

____

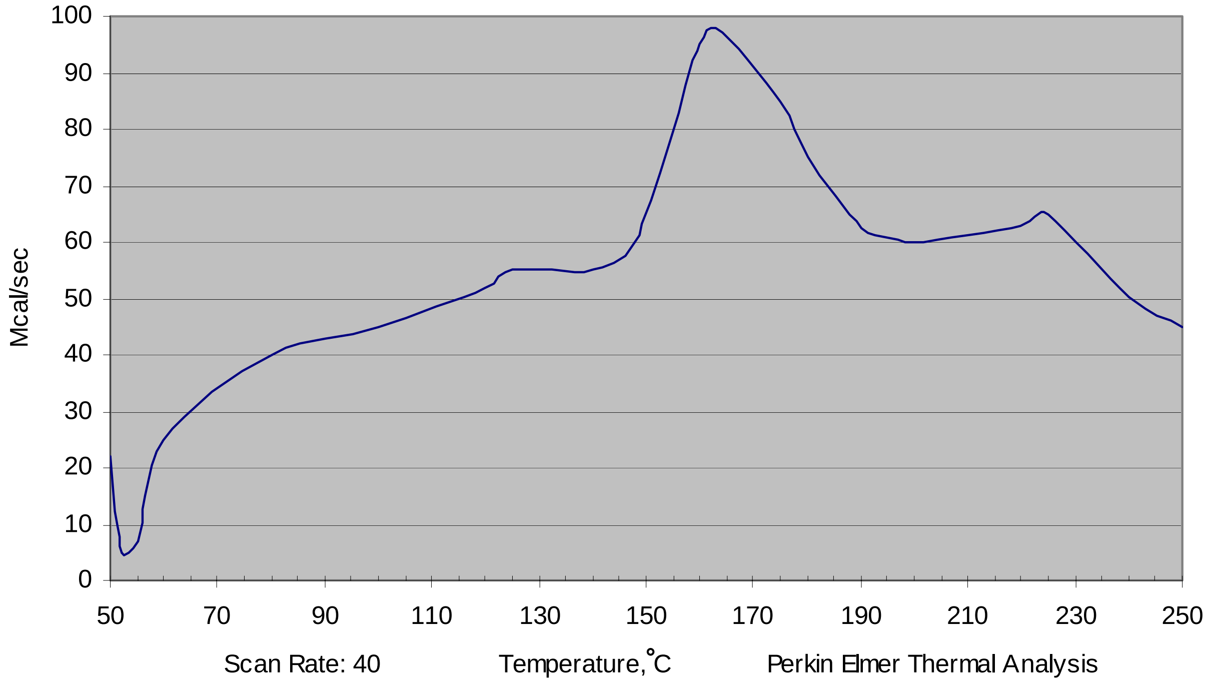
Customer Return Instructions: __________ Customer will pick up material within 14 days

__________ No Charge for material

__________ Dispose @ Customer Cost

Recorded by: _________________________ Date: _________________________________

Appendix J. DSC Curve for PP from Joe's Plastics Company, August 2004



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